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ROCKS AND STRUCTURE OF THE QUARTZ SPRING AREA NORTHERN PANAMINT RANGE, CALIFORNIA

By JAMES F. McALLISTER
Prepared in Cooperation With the
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BY JAMES F. MCALLISTER *

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ABSTRACT

The report describes the stratigraphy, igneous petrology, and the main features of the structure in the Quartz Spring area. The formations and the structure are shown on a large-scale topographic map and in structure sections. The Quartz Spring area covers about 50 square miles in the northern part of the Panamint Range, Inyo County, California. It lies near the southwestern border of the Basin and Range Province.

The stratigraphy, except for Quaternary deposits that cover about one fourth of the area, consists of Paleozoic sedimentary rocks preponderantly dolomite and limestone, representing each system from Cambrian to Carboniferous, as outlined below. No surface of erosion (unconformity) has been recognized between any of the formations or systems within the area.

	Feet
*Tihvipah limestone—Pennsylvanian. Limestone, somewhat shaly	200±
*Rest Spring shale—Pennsylvanian(?). Olive-gray shale, siltstone, and local quartzite	310±
*Perdido formation—Mississippian. Brownish siltstone, dark-gray limestone and chert, some conglomerate and shale	610±
*Tin Mountain limestone—Mississippian. Conspicuously dark gray limestone, shaly in lower part, a little chert	475
*Lost Burro formation—Upper and Middle(?) Devonian. Light- and dark-gray dolomite and limestone, thin sandstones at top and bottom	1,525
*Hidden Valley dolomite—Lower Devonian (65 feet) and Silurian. Dolomite, cherty in lowest part	1,365
Ely Springs dolomite—Upper Ordovician. Light-gray dolomite in upper part; lower part conspicuously dark-gray dolomite, cherty	940
Eureka quartzite—Middle Ordovician. Upper part massive vitreous quartzite; lower part somewhat shaly and ferruginous quartzite	400
Pogonip limestone—Lower Ordovician. Dolomite and limestone, some shale, chert, and sandy beds	1,440
Nopah formation—Upper Cambrian. Light- and dark-gray dolomite, shaly limestone at base	1,600
*Racetrack dolomite—Middle(?) Cambrian. Gray dolomite; some chert in lower part	1,900±
Total thickness	10,765±

The Paleozoic rocks have been deformed by thrust faults, folds related to the thrusts, normal faults, and small intrusions. The age of the structures cannot be determined here closer than that they are younger than early Pennsylvanian and older than Quaternary. The only discernible effect of the structures on the present topography has been to influence differential erosion.

The largest exposures of intrusive alkalic rocks in the northeastern quadrant of the area are not more than half a mile wide or 2 miles long. The alkalic rocks, in dikes, sills, and chonoliths, are characterized by abrupt changes in texture and in the proportion of mafic minerals. Most of the textures, whether granular or porphyritic-granular, are also trachytoid. The proportion of mafic minerals ranges from 3 percent in leucosyenite to 42 percent in the groundmass of porphyritic aegirine-augite syenite. The degree of saturation by silica ranges from undersaturated nepheline-syenite, through saturated syenite, to oversaturated aplite. The most abundant type is trachytoid leucosyenite, which consists of about 97 percent microperthite. Much of the microperthite, which is the most prevalent mineral in the entire suite of rocks, is a late partial replacement of orthoclase by albite. The other rocks described are: melanite nepheline-syenite, hastingsite nepheline-syenite, aegirine-augite monzonite, aegirine-augite monzonite-porphyry, aegirine-augite syenodiorite, syenite pegmatite, nordmarkite, and aplites. The most favored theory of origin of the alkalic rocks in the Quartz Spring area is that a late differentiate from a quartz-monzonite batholith was desilicated on passing through much carbonate rock and late magmatic fluids deuterically added soda.

* Geologist, U. S. Geological Survey. Ph.D. dissertation, Stanford University, 1951. Manuscript submitted for publication April 1952. Publication authorized by the Director, U. S. Geological Survey.

* New names.

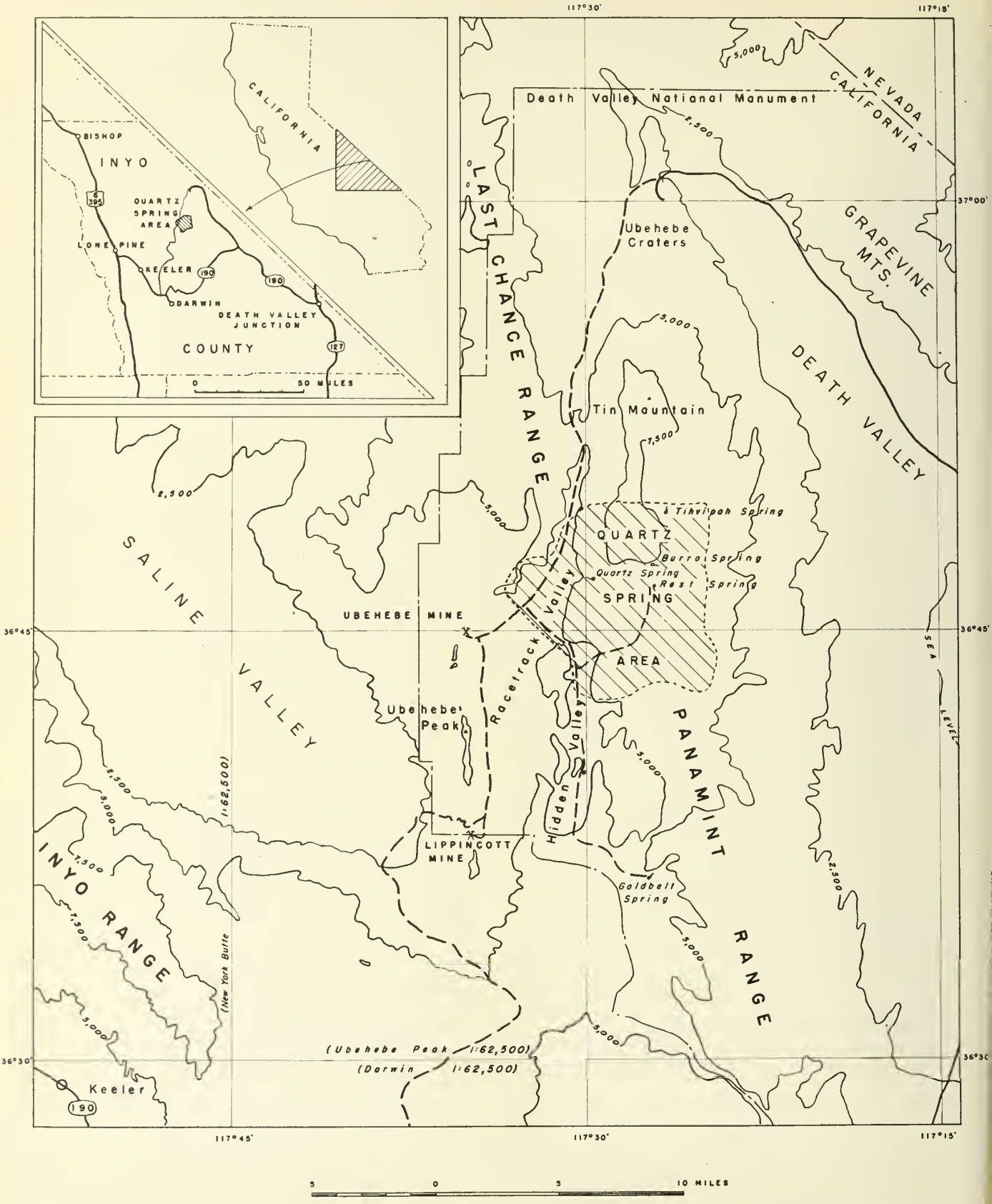

FIGURE 1. Index map showing location of the Quartz Spring area, Inyo County, California.

INTRODUCTION

The bare mountains around Death Valley, such as the Panamint Range, are a magnificent display of rocks from the pre-Cambrian to the Cenozoic in a complexity of structure. Only the broadest outlines of the geology had been known and little of it has been mapped. In the vast display attention was focused for this report on a small area that extends westward from the crest of the Panamint Range at the northern end, and that lies around Quartz Spring. From it has come a description of the marine sedimentary rocks that extend from well up in the Cambrian system to partly through the Carboniferous system, a piecing together of these formations into a stratigraphic column, the petrology of some alkalic rocks that are rare in California, and the description of a sample of the structure in the Death Valley region. The distribution and structure of the rocks are illustrated in geologic sections and on a large-scale geologic and topographic map. The stratigraphy contributes a local standard in the broad expanse between two localities where the detailed stratigraphy is known, the Inyo Range to the west and the Nopah Range to the southeast. The local standard has been adequate for mapping detailed geology of mine areas and much of the regional geology in the Ubehebe Peak quadrangle.

The Quartz Spring area lies about 4 miles south of Tin Mountain on the northern tip of the Panamint Range in Inyo County, eastern California, and is just within Death Valley National Monument (fig. 1). The area (pl. 1), irregular in outline, covers about 50 square miles, and extends from the upper part of the eastern slopes of the Panamint Range westward across the rolling summit, and beyond Racetrack Valley into the foothills of the Last Chance Range (figs. 2 and 3). The area has a maximum relief of 4,200 feet, rising from 4,200 feet above sea level in Racetrack Valley to 8,400 feet, north of Burro Spring. (See pl. 1).

An unimproved road extends from the Death Valley paved highway at Ubehebe Craters southward 20 miles to the junction of the Hidden Valley and Racetrack roads (see fig. 1). This was the only road to the area at the time of the principal field work, from 1937 to 1939. Subsequently a southern access from the Lone Pine-Darwin highway was opened through the southern end of Saline Valley and up to Racetrack Valley. This road, although more direct from Owens Valley, is steep, narrow, and rough. The route was shortened, avoiding much of the roughest part, by construction of a private road (finished in 1951 and not shown in figure 1) from the divide southeast of Saline Valley to the northern road at Goldbelt Spring. At times the northern road is roughened by torrential runoff, and the southern road through Saline Valley is made impassable. Within the Quartz Spring area in 1937-1939 it was possible to drive through Racetrack Valley, into Hidden Valley, and with difficulty past Rest Spring to within 2,000 feet of Burro Spring. In 1950 the road was scraped and extended to the east crest of the Panamint Range, about 2 miles N. 55° W. of Rest Spring. A side road from the Racetrack Valley road was passable 1½ miles to a camp site near Quartz Spring.

The arid climate accounts for a lack of streams and a scarcity of springs. There are only four springs in the area—Quartz, Rest, Burro, and Tihvipah. They are unusable seeps except when cleaned and protected from abuse by wild burros. No water is available between Grapevine Springs in Death Valley and Quartz Spring. The nearest water to the south is at Goldbelt Spring, which is easily reached by a road through Hidden Valley (see fig. 1). Mendenhall (1909, pp. 32-33) reported that Rest Spring and Burro Spring each yielded about 3 barrels of water daily and Goldbelt Spring about 20 barrels daily. Precipitation from summer showers and winter snowfall is highly erratic from year to year, and is somewhat greater in the higher places. No measurements of precipitation are available. Because of the climate and relief, vegetation is sparse, soil is poorly developed, and the exposures of bedrock are excellent.

Previous Work. Earlier geologic work in the area was cursory. The earliest reference to the geology of the Panamint Range is in the report by Whitney (1865, p. 474), ". . . of their geology little is known except that the rocks are crystalline and metamorphic." Gilbert in the U. S. Geographical Survey West of the 100th Meridian described the range merely as "mountains of upheaval" (Gilbert, 1875, p. 125). Fairbanks (1894, p. 473) added little to the knowledge of its geology in recording "Limestone, quartzite, slate, and mica schist form the predominating rocks. Areas of granite are, however, found in places." He also noticed there had been some indication of intense diastrophism (Fairbanks, 1896, p. 67). Mineral deposits and types of associated rocks in the Ubehebe district, southwest of the Quartz Spring area, have been described briefly in *Copper Resources of California* (Aubury, 1908, pp. 301-312), and in other reports about mines and mineral resources of Inyo County, published by the California Division of Mines (see Norman and Stewart, 1951).

No maps that include the Quartz Spring area have been published with more information than was on the early reconnaissance maps by Spurr (1903, pl. 1), Ball (1907, pl. 1), and Waring (1917). Spurr called all the rocks there Silurian, which then included Ordovician; Ball mapped them as the Pogonip limestone of Ordovician age, and a little quartz-monzonite porphyry; and Waring designated some of the rocks as Cambrian, as well as Silurian. Ball's map is the source of the geology of the northern Panamint Range as shown on the latest geologic map of California (Jenkins, 1938). Other geologic maps of areas in the Panamint Range do not include the northern end of the range.

More recent publications refer only to the central and southern parts of the Panamint Range. Murphy (1932) mapped and described an area in the south-central part of the range, and White (1940) published on the antimony deposits of the Wildrose Canyon area, entirely in pre-Cambrian rocks. Hopper (1947) in his geologic section from the Sierra Nevada to Death Valley included a strip across the central part of the Panamint Range, and earlier published an abstract of the stratigraphic information (Hopper, 1939).

Other reports on adjacent regions have been more applicable. Some of the formations of Death Valley described by Noble (1934, pp. 173-178) occur in the Quartz Spring area, and a part of Hazzard's (1937) stratigraphic sequence in the Nopah and Resting Springs Mountains is similar to the sequence in the area. Some of the formations used by Hazzard were adopted and others could be generally correlated, whereas the earlier, reconnaissance de-

FIGURE 2. Western front of Panamint Range at Quartz Spring.

FIGURE 3. Southeastern foothills of Last Chance Range from Racetrack Valley, showing the stratigraphy from Racetrack dolomite to Ely Springs dolomite. *Photograph by Ward Smith.*

scription of rocks in the much closer Inyo Range (Kirk, 1918) could not be successfully applied. Recent mapping by Ward Smith and C. W. Merriam (reports in preparation) shows that most of the Paleozoic formations of the New York Butte quadrangle in the Inyo Range and of the Quartz Spring area are readily correlated.

Field Work. Field work in the Quartz Spring area was started by a brief reconnaissance during several weeks in the summer of 1937, and a week in the spring of 1938. The main field work was done from August 1938 to January 1939, and the final field checking was concluded during two weeks in April 1940 and several days in 1948 and 1949.

A topographic map prepared by enlarging the relevant part of the U. S. Geological Survey's Ballarat quadrangle map was inadequate as a base for the geologic mapping. A topographic sketch map (pl. 1) therefore was made, without assistance, by triangulating on a lightweight improvised plane table with a Brunton compass attached to a Duralumin straightedge. The difficulty of measuring, unaided, a base line over hilly ground was met by using a Brunton clinometer as a hand level to measure the vertical distance from valley to hilltop, and the clinometer also to measure the vertical angle, so as to calculate the horizontal distance. The base line thus measured between two hills near Rest Spring, when drawn to a scale of 2,000 feet to an inch, was slightly less than 3 inches on the map, which was somewhat short for the triangulation network about 20 inches in diameter. Altitudes used in sketching contour lines at a 100-foot interval were determined with an aneroid barometer, although there was no control for atmospheric changes in pressure. The datum is approximately sea level. On the map (pl. 1) most names of topographic features were applied for convenience in reference and have not been sanctioned by the Board on Geographic Names, so they should be considered a temporary expedient. Two of the names that were applied to new formations, Perdido and Tihvipah, have appeared on no other map.

Acknowledgments. The National Park Service, through an appointment of the writer as Student Technician in Geology to assist Ranger Naturalist H. D. Curry in Death Valley Monument during the summer of 1937, provided him the opportunity to select the area. Mr. Curry proposed the Quartz Spring area, among several others, and was generous with his knowledge of regional geology. His association with Levi Noble of the U. S. Geological Survey, during previous field work in other parts of the Death Valley region, provided a link between Mr. Noble's fundamental work and this later work. Mr. Curry, while on reconnaissance trips with the writer through the Quartz Spring area in 1937, pointed out the sequence of Eureka quartzite and Ely Springs dolomite, which proved to be one of the keys to the stratigraphy and structure of the area. It is a pleasure also to acknowledge innumerable courtesies that officials of the National Park Service extended during several seasons of independent field work.

The principal part of the work in the Quartz Spring area was planned and discussed with Dr. Eliot Blackwelder and Dr. A. O. Woodford at Stanford University. Dr. S. W. Muller was helpful particularly with the paleontologic and stratigraphic aspects of the work, and Dr. A. C. Waters, the petrologic part. Dr. Waters arranged

for W. H. Herdsman's chemical analysis of the nepheline-syenite.

During field work 10 years later in the adjacent Ubehebe Peak quadrangle the writer, assisted at different times by W. R. Eames, A. F. Agnew, E. M. MacKevett, Jr., M. W. Ellis, and R. F. Johnson, measured some of the sections and collected some of the fossils that have been used in this report. This work was part of the U. S. Geological Survey's program in cooperation with the California State Division of Mines, and was under the supervision of Ward Smith of the U. S. Geological Survey. Fossils collected during work in the Ubehebe Peak area have been identified by paleontologists of the U. S. National Museum and of the U. S. Geological Survey, and credit to each paleontologist is given with the data. The faunal lists and their stratigraphic significance are substantial contributions.

The report was critically read by Drs. S. W. Muller, A. C. Waters, W. C. Smith, and C. W. Merriam, who made greatly appreciated suggestions for improvement.

The section on economic geology was contributed by Lauren A. Wright and Thomas E. Gay, Jr., of the staff of the California Division of Mines. The location of the mines and prospects shown on plate 1 was determined by them in 1951, when they inspected the properties.

SEDIMENTARY ROCKS

Sedimentary rocks compose somewhat more than 90 percent of the area shown on the geologic map (pl. 1). Except for Quaternary deposits, which cover about one fourth of the area, limestone and dolomite constitute by far the major part of the stratigraphic column (pl. 2). Shale, although it constitutes a small proportion of the stratigraphic sequence, crops out extensively, and like the equally small proportion of quartzite, makes good stratigraphic markers. Chert, conglomerate, and breccia are minor constituents of the sedimentary sequence.

Formations were established primarily by selecting persistent and easily distinguishable lithologic units that could be mapped on a scale of 1:24,000 to show adequately the stratigraphy and structure of the region. Previously named formations were used when it was possible to recognize them by advice of H. D. Curry, by limited personal observation in some areas where the formations had been described, or by comparison with published descriptions. The age of some of the formations has been assigned tentatively, as diagnostic fossils have not been found in them or the fossils are too poorly preserved to be precisely identified. Some of the formations that are primarily good mappable lithologic units may cross systemic boundaries.

Rocks older than Quaternary range in age from Middle (?) Cambrian to Pennsylvanian (fig. 6). Those from Cambrian to late Devonian can be correlated reasonably well with formations that have been established in the Death Valley region and eastern Nevada (see Nolan, 1943, pp. 148-156). Mississippian and Pennsylvanian units, however, are more difficult to compare with those in published stratigraphic sections.

Pre-Cambrian rocks, which are well represented in the central and southern parts of the Panamint Range (Murphy, 1932, p. 337, pl. 4; Hopper, 1947, pp. 402-403, pl. 1), do not crop out in the Quartz Spring area. The area also lacks exposures of most of the Cambrian rocks that occur southward in the central part of the Panamint Range (Hopper, 1947, pp. 403-407), eastward in the Grapevine Mountains of the Amargosa Range (Curry, 1937, oral communication), northwestward in the Inyo Range (Kirk, 1918, pp. 25-28), and probably northward in the Last Chance Range.

Rocks younger than those exposed in the area occur nearby. Limestones of late Pennsylvanian and Permian age continue the stratigraphic sequence several thousand feet upward, between Racetrack Valley and Saline Valley, only 5 miles west of the area (McAllister, 1946-1949, unpublished data of the U. S. Geological Survey); and at least part of the same sequence lies faulted against the eastern front of the Panamint Range (Ball, 1907, p. 203, fig. 17, pl. 1), about 10 miles southeast of the area. Triassic rocks are extensively exposed in the Inyo Range (Kirk, 1918, pp. 47-48, pl. II). Continental Tertiary deposits starting with fossiliferous beds of Oligocene age (Stock and Bode, 1935) are exposed in the Grapevine Mountains east of Death Valley. The absence of sedimentary rocks from Permian to Pliocene age in the Quartz Spring area not only leaves a wide gap in the history of sedimentation but also produces difficulties in dating events in the structural history.

No unconformity, representing any sort of erosional gap in the sedimentary sequence, has been recognized at the boundaries of the Paleozoic systems in the Quartz Spring and adjacent areas, where every boundary is well exposed. A disconformity marked by local conglomerate without noticeable angular discordance below it may occur in the Perdido formation, but within the Mississippian series. Discontinuities in the sedimentary record, either disconformities or angular unconformities of such low angle of discordance that the discordance is not obvious, or some other types of hiatus, are to be expected in the local Paleozoic sequence. The known faunas are widely spaced through the sedimentary sequence. The fact that fossils of intermediate ages have not been found, however, is insufficient basis for postulating a corresponding absence of sedimentary rocks of those ages. The existence of significant gaps perhaps may be recognized after much more extensive mapping and correlation.

Racetrack Dolomite (Middle(?) Cambrian)

Name and Occurrence. The oldest rock unit in the sedimentary sequence of the Quartz Spring area is here named the Racetrack dolomite for Racetrack Valley, the long depression draining southward to The Racetrack playa from a low divide between Tin Mountain and Dry Mountain. The valley separates the northern end of the Panamint Range from the southern foothills of the Last Chance Range. The type locality of the Racetrack dolomite is in the Last Chance foothills on the western side of Racetrack Valley, about 3 miles west of Quartz Spring. More precisely, the type locality extends from the southern tip of the spur west of the Hidden Valley road junction, for roughly 7,000 feet to the saddle north of the U. S. Geological Survey bench mark at 5,330 feet above sea level (see fig. 3). The bench mark is shown on the Ballarat quadrangle.

The base of the Racetrack dolomite cannot be defined satisfactorily in the Quartz Spring area because alluvium overlaps the lowest exposures. The top is limited by the Nopah formation. The Racetrack dolomite crops out at no other place in the mapped area.

Lithology. Gray dolomite is the conspicuously predominant rock of the formation. The color varies from dark gray to very light gray or grayish yellow, producing from a distance a salient effect of thick bands (see fig. 3). Closer inspection reveals that bedding is very much thinner than the color bands, and thinner than the spacing of well-developed joints which run parallel to the stratification. Many of the beds have minutely wavy bedding planes and small blotches of lighter or darker gray. Obvious variations in lithology are slight: there is some irregularly distributed brown-weathering nodular chert and in the lower part some rather platy silty dolomite.

The following section was measured at the type locality:

Nopah formation.
(Conformable contact.)

Racetrack dolomite:	Feet
7. Somewhat streaky light-gray dolomite grades into darker gray near base	450
6. Light grayish buff dolomite contains a few thin dark-gray beds	150
5. Very dark gray dolomite contrasts sharply with lighter dolomite above and below; in detail, very irregular lighter mottling extends in all directions; some small vugs of quartz	200
4. Light-gray dolomite weathers creamy gray somewhat mottled by tan; a few irregular streaks of darker gray do not detract from its conspicuousness as a marker	30
3. Medium-gray dolomite; closely spaced sinuous mottling along bedding; widely spaced joints; some chert nodules	690
2. Somewhat platy dolomite that weathers pale yellowish brown, includes a very little pale reddish brown silty dolomite. About 30 feet from the base a massive bed of gray dolomite, 5 feet thick, lies within the brownish zone	55
1. Dark-gray medium-grained dolomite, irregularly banded with lighter gray dolomite in layers about 1 inch thick, for about 220 feet above the base; in upper part some masses of chert up to 2½ feet long, ovoid in section; possible faults	325±
	1,900±

Thickness. The stratigraphic thickness of the Racetrack dolomite in the Last Chance foothills is about 1,900 feet. Possible unmapped faults make questionable the measurement of the lowest units.

Age and Correlation. Although no fossils have been found in the Racetrack dolomite, the formation is presumably Middle Cambrian in age, if not in part early late Cambrian. No detectable stratigraphic break separates it from the overlying Nopah formation of Late Cambrian age. In stratigraphic position and lithology the Racetrack dolomite corresponds to the upper part of Hazzard's Cornfield Springs formation in the Nopah Range. The entire Cornfield Springs formation was provisionally assigned by Hazzard (1937, p. 319) to the Middle Cambrian, with the reservation that the unfossiliferous upper part could be early Upper Cambrian.

Nopah Formation (Upper Cambrian)

Name and Occurrence. The Nopah formation in the Quartz Spring area is considered to be essentially the same unit as that in the northern half of the Nopah Range in the southeastern corner of Inyo County, California, named by Hazzard (1937, p. 320). In the Quartz Spring area it is underlain by light-gray Racetrack dolomite and overlain by Pogonip limestone. The Nopah formation makes cliffs or steep slopes that tend to become smooth, except in detail; thus it is topographically indistinguishable from the underlying Racetrack dolomite. In the mapped area the only exposures of the Nopah formation are on the ridge north of bench mark 5,330 and on a spur east of the bench mark, in the Last Chance foothills (see pl. 1 and fig. 3).

Lithology. The Nopah formation rather uniformly consists of dolomite, except for minor quantities of shale, limestone, and chert. The color ranges from cream through light gray to very dark gray, the dark gray predominating. Cream-colored dolomite, although subordinate, crops out in conspicuous bands that can be traced continuously across the area of exposure. In general aspect the banding is similar to that of the Racetrack dolomite.

The lowest part of the formation consists of medium dark gray dolomite, which at the base contains medium- to light-gray limestone interbedded with pale-olive shale and brown-weathering silty and cherty limestone. Shaly partings in the limestone appear tan or pinkish and contain some primitive brachiopods. Also trilobites occur in some of this limestone.

Above the basal unit of the Nopah formation there is a prominent layer of cream-colored dolomite, about 30 feet thick, overlain by a succession of dark- and light-colored dolomite layers, which crop out as conspicuous bands across the hills. The following generalized tabulation of the sequence of light and dark layers of dolomite was derived from a structure section that lacked details, and was later verified on aerial photographs that showed the banding clearly. The thickness of each layer therefore is only approximate.

Pogonip limestone.
(Conformable contact.)

Nopah formation:	Feet
9. Dark-gray dolomite	120
8. Cream-colored dolomite	30
7. Medium-gray to dark-gray dolomite; small gastropods	535
6. Cream-colored dolomite	30
5. Dark-gray dolomite	125
4. Very light gray dolomite	225
3. Dark-gray dolomite	125
2. Cream-colored dolomite	30
1. Medium dark gray limestone; lower 250 feet contains limestone, in places silty or cherty, weathering brown, interbedded with light-olive shale; trilobites in limestone and primitive brachiopods in tan or pinkish shaly partings	380
	1,600

(Conformable contact.)
Racetrack dolomite.

Thickness. The thickness of the Nopah formation in the Last Chance foothills was calculated in a structure section to be approximately 1,600 feet.

Age and Correlation. Fossils have been found only in the silty calcareous lowermost unit (unit 1 of the stratigraphic section) and in gray dolomite (unit 7) about 500 feet below the upper contact of the Nopah formation. From the lower zone (unit 1) the following fossils were identified by G. Arthur Cooper (written communication, 1949) of the U. S. National Museum:

U-197 * Lingula sp.
Obolus sp.
Acrotreta cf. A. idahoensis Walcott

* Field number of collection.

From the same zone at another locality the following fossils were identified by A. R. Palmer (written communication, 1950) of the U. S. Geological Survey:

U-959 Linguloid fragments
Minute acrotretid brachiopods
Elvinia n. sp.
Aphelaspis sp.
Linnarssonella girtyi Walcott
Ptercephalia?

Palmer commented that the fossils "belong to the *Elvinia* zone of the Franconian stage, which places them at the bottom of the middle division of the Upper Cambrian."

From the upper fossiliferous zone (unit 7) the following small silicified gastropods were identified by Josiah Bridge (written communication, 1950) of the U. S. Geological Survey:

U-241 Matherella cf. M. saratogensis Walcott
Sinuopea, 3 or 4 species—all undescribed
Strepsodiscus sp.
New genus—new species—a small uncoiled form with a triangular cross section
Unidentified plates

"This fauna appears to correlate with a fauna in the upper part of the Eminence formation of Missouri particularly the so-called Proctor horizon and also with the Hoyt limestone of New York. The rather distinctive sinistrally coiled genus *Matherella* is common to all three areas. The fauna is very high Upper Cambrian."

The Nopah formation in the Quartz Spring area can be correlated with the Nopah formation of Late Cambrian age at the type locality in the Nopah Range (Hazzard, 1937, pp. 320-321) by its stratigraphic position below the Pogonip limestone, similarity of lithology, and the *Elvinia* zone at the bottom. Whereas the details of light and dark banding appear to be local, the basal shaly unit of the formation at the two localities is a good marker of the lower limit. The upper limits of the formation in the Nopah and Quartz Spring areas may not be strictly equivalent.

Upper Cambrian rocks in the Inyo Range 30 miles northwest of the Quartz Spring area cannot be correlated —from Kirk's (1918, pp. 31-32) description—with the Nopah formation. The Inyo rocks consist largely of arenaceous limestones and shales that weather to bright colors, sandstones, and impure limestones, similar to Turner's Emigrant formation in the Silver Peak quadrangle, Nevada (Turner, 1902, p. 265). The Late Cambrian age of the formation in the Inyo Range has been questioned by Hazzard (1937, p. 322). Upper Cambrian formations at other places in the Great Basin also are difficult to correlate with the Nopah formation by the described lithology. But the Mendha limestone in the Pioche district (Westgate and Knopf, 1932, pp. 11-12) is like the Nopah formation.

Pogonip Limestone (Lower Ordovician)

Name and Occurrence. Pogonip limestone is the name applied originally by King (1878, pp. 187-195) to all beds between the Prospect Mountain quartzite (Lower Cambrian) and the Eureka quartzite (Middle Ordovician), as at Pogonip Ridge, Hamilton, Nevada, which is the type locality. Hague (1883, pp. 253-263) limited the Pogonip limestone to the beds between what is now called Dunderberg shale (Upper Cambrian) and the Eureka quartzite. Walcott proposed restricting Pogonip further, but the U. S. Geological Survey uses the name in the broader sense (Wilmarth, 1938, pp. 1689-1690).

The Pogonip limestone in the Quartz Spring area comprises the rocks above the Nopah formation and below the Eureka quartzite. The Pogonip here contains a variety of rocks, but limestone is conspicuous and is retained as the lithologic part of the name. A typical section is exposed in the Last Chance foothills, about 2½ miles west of Quartz Spring (see fig. 3).

Lithology. The general aspect of the Pogonip here is mouse-gray dolomite and limestone containing several more or less conspicuous dark reddish brown bands. Closer observation shows that it contains considerable siliceous material, both chert and sandy dolomite, and three well-marked zones of buff-weathering shaly beds. The reddish brown-weathering zones consist of thin cherty beds that appear crinkled or wavy, and merge at points of greatest irregularity, producing a structure that resembles piles of crepe; nodules and minute flat lenses of limestone remain isolated in the cherty rock (fig. 4).

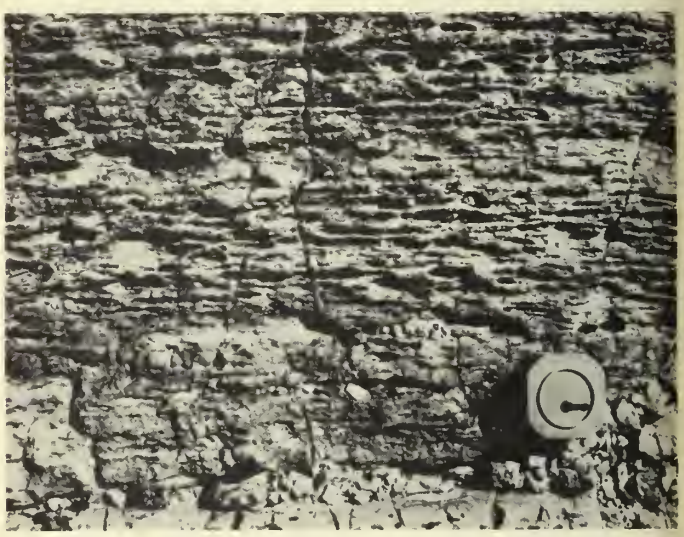

FIGURE 4. Crepe structure in a siliceous part of the Pogonip limestone.

The beds make diagnostic markers of the Pogonip limestone throughout the region, as even through considerable contact metamorphism the crepe structure persists. Another distinctive feature of the formation is a conspicuous zone of large gastropods, which in outcrops appear as spirals sufficiently persistent to be considered a lithologic characteristic of that part of the formation.

Isolated outcrops of some parts of the Pogonip limestone may be confusingly similar to some other formations. Some beds in the Nopah and Racetrack formations are similar to the darker lowest dolomite of the Pogonip, which is distinguished, however, by light-gray chert and the somewhat mouse-gray color of the weathered rock. The uppermost Pogonip, the part that is above the gastropod zone, if it lacks the usual brown-weathered streaks and lenses of sand may be indistinguishable from mouse-gray dolomite in the Hidden Valley dolomite. Despite these exceptions, the Pogonip limestone is a distinctly mappable unit.

The following detailed section, except the bottom unit (no. 1), was measured with a tape along a spur on the west side of Racetrack Valley opposite Quartz Spring.

The lowest unit was measured on the next ridge to the west, about 4,000 feet from the first:

	Feet
Eureka quartzite.	
(Conformable contact.)	
Pogonip limestone:	
8. Gray dolomite, in general medium gray although some beds are dark gray, weathering mouse gray; fine-grained to medium-grained; sandy dolomite in irregular streaks somewhat contorted in detail, expanding here and there into sandy pockets, especially characteristic of upper part. The sandy element weathers brown. A zone of *Palliseria* and *Maclurites* is so exceptionally persistent near the middle that the gastropod spirals can be considered a lithologic characteristic	485
7. Light-buff or yellowish shaly limestone, sparsely fossiliferous; very poorly exposed; forms shoulders on spur	50
6. Brown-weathering siliceous beds, largely chert, tend to predominate over the gray limestone, which remains in nodules and lenses where the thin siliceous layers touch at undulations, producing a crepe structure. The proportion of siliceous material decreases gradually upward; and decreases abruptly at the base, where the lowest 35 feet is a platy gray limestone with ochreous irregular partings, and contains fragments of poorly preserved fossils. The shaly rock at the base emphasizes the cliff-forming quality of the unit, which makes it one of the most conspicuous of the Pogonip	185
5. Float of light-brown shale containing fossil fragments; does not crop out along line of section	145
4. Light-gray limestone and dolomite, weathering brownish gray, contains many siliceous beds, up to 4 inches thick, that tend to merge at crenulations making a crepe structure, especially in lower half, which from a distance is browner than the mouse gray of the upper half. About 70 feet from the base of the unit, some intraformational breccia of particles about one-half inch thick in a clastic matrix; some cross-bedding; numerous veinlets of white calcite	120
3. Buff-weathering shaly dolomite crops out poorly	60
2. Light-gray dolomite, much of which weathers light brown or light-brownish gray, contains brown-weathering sandy streaks and a little chert in the lower part, where there are also scattered clusters of small but conspicuous quartz crystals which in some places make an open network pattern	150
1. Medium-gray dolomite, locally limestone weathers a mouse gray, and contains some flat lenses of light-gray chert, especially about 80 feet above the base of the formation. The mouse-gray color, the chert, and occasional limestone distinguish this basal unit of the Pogonip from the underlying Nopah formation	245
(Conformable contact.)	1,440
Nopah formation.	

Thickness. The stratigraphic thickness of the composite section described in detail above is 1,440 feet. The measured section is a single continuous sequence except for the basal unit of 245 feet, which is buried in alluvium at that locality. The basal unit was measured in an excellent sequence extending unbroken from the Racetrack and Nopah formations below the Pogonip limestone and continuing into the Pogonip so that unit 2 of the Pogonip was matched at the two localities.

Age and Correlation. The most distinctive fauna of the Pogonip limestone in the Quartz Spring area occurs near the middle of the uppermost unit (unit 8) and consists of abundant conspicuous *Maclurites, Palliseria,* and *Receptaculites,* which have been considered good markers of that part of the Ordovician of the Great Basin that is of Chazy age. A fauna from unit 5 of the detailed section of the Pogonip is definitely Lower Ordovician. It is not yet known, however, whether the lowermost 400 feet (units 1 and 2) includes also Upper Cambrian rocks.

From about 300 feet below the upper boundary of the Pogonip limestone (unit 8) the following fossils were identified by G. Arthur Cooper (written communication, 1949):

U-92 Palliseria longwelli (Kirk)
Maclurites sp.
Receptaculites sp.
Porambonites sp.

"This *Receptaculites* or *Palliseria* zone of the Pogonip is widespread in the Great Basin area."

The following fossils collected by R. L. Parker from shaly unit 5 of the Pogonip limestone were identified by Josiah Bridge, in consultation with G. A. Cooper (written communication, 1951):

P-70 Archeorthis costellata Ulrich and Cooper
Kainella(?) finalis (Walcott)
Bellfontia sp.
Hystricurus tuberculatus (Walcott)

"This fauna . . . is definitely of Lower Ordovician (Canadian) age."

Spurr (1903, p. 188) was the first to report on Pogonip in this region. He was informed by F. B. Weeks that rocks probably corresponding to the Pogonip formation of Eureka, Nevada, occur at Grapevine Peak at the northern end of the Amargosa Range and probably continue to Pyramid Peak in the central part of the range. The Amargosa Range is the first range east of the Panamint Range, on the opposite side of Death Valley. Weeks reported Pogonip fossils also from the northern part of the Panamint Range (Spurr, 1903, p. 202). At a later date Ball (1907, pp. 164-165) described the extensive occurrence of Pogonip limestone in the Amargosa Range. His reconnaissance map, however, includes under the symbol for Pogonip what is now known to be much more of the Paleozoic sequence. Ball's map of the northern end of the Panamint Range is even more generalized, where all the Paleozoic rocks from Cambrian through Carboniferous are shown as Pogonip limestone, except in the eastern foothills of the range, where Pennsylvanian rocks are distinguished. The description (Ball, 1907, pp. 202-203) shows that Ball did observe Pogonip in the present sense of the term, but he failed to separate it from Eureka quartzite and some higher formations.

Most of the Pogonip limestone of the Quartz Spring region closely resembles the Pogonip(?) in the Nopah area described by Hazzard (1937, p. 324). But the lowest part in this northern Panamint area, especially the lower boundary, has not been correlated precisely with the Pogonip elsewhere. The two lowest units, 1 and 2 of the section described above, as nearly as can be determined from Hazzard's descriptions (1937, p. 276), correspond more closely to 400 feet of the uppermost member (86 in Hazzard's section) of the Nopah formation rather than to the basal part of the Pogonip(?) in the Nopah-Resting Springs region. These two units are included in the Pogonip here on the basis of lithology and of ease in mapping. Their mouse-gray color and chert lenses are characteristic of the Pogonip and not of the Nopah formation.

At the eastern base of the Panamint Range about 40 miles southeast of Quartz Spring, Hopper (1947, p. 407) recognized but did not map Hazzard's Pogonip(?) dolomite. Hopper included it in a unit, approximately 9,000 feet thick, of undifferentiated Cambrian and Lower Ordovician dolomite and limestone.

In the Inyo Range rocks of the same age and lithology as the Pogonip limestone in the northern part of the Panamint Range were described by Kirk (1918, pp. 34-35), but he declined to call them Pogonip because he considered that the term was too loosely used. Kirk did not subdivide the Ordovician rocks for the reconnaissance map of the Inyo Range.

The Tank Hill limestone in the Pioche district (Westgate and Knopf, 1932, pp. 14-15), which was considered to be essentially the same as the upper part of the Pogonip limestone of the Eureka district, seems equivalent to the upper part of the Pogonip limestone in the Panamint Range. The Yellow Hill limestone at Pioche (Westgate and Knopf, 1932, p. 14) probably corresponds to part of the lower unit of the Pogonip in the Panamint area. The Pogonip limestone in the Ely quadrangle (Spencer, 1917, p. 24) was described in too general terms to correlate it on the basis of lithology.

Eureka Quartzite (Middle Ordovician)

Name and Occurrence. The Eureka quartzite was named by Hague (1883, pp. 253, 262) in the Eureka, Nevada, region. Kirk (1933, in Wilmarth, 1938, pp. 706-707), with the approval of the U. S. Geological Survey, designated ". . . the exposures on southwest slope of Lone Mountain as the type section of the formation, because here it is completely exposed, together with overlying Lone Mountain limestone and underlying Pogonip limestone, while it is not exposed at Eureka, although it is poorly exposed in Eureka region. The Lone Mountain section is about 18 miles northwest of Eureka, and was known to Hague. . . ." A stratigraphic section of Lone Mountain, showing the position and thickness of the Eureka quartzite, was published by Merriam (1940, p. 20).

Exposures of Eureka quartzite are widely distributed in the Quartz Spring area, but nowhere is it as continuous or well exposed in cross section as on the mountain scarp about 3 miles southwest of the area, where the thickness was measured for the local standard (fig. 5). Within the Quartz Spring area the quartzite crops out in the Andy Hills near the southern border, on the southern flank of Whitetop Mountain near the eastern border, on the steep slopes east of Quartz Spring, and in the Last Chance foothills. The Eureka quartzite lies stratigraphically above the Pogonip limestone and below the Ely Springs dolomite.

Where erosion has reduced the topography to a late stage, the Eureka quartzite forms rough hills, and where the topography is less subdued it makes blocky cliffs. The more massive upper part of the quartzite breaks into large angular joint blocks commonly 1 foot or 2 feet thick but as much as 6 feet thick.

Lithology. The Eureka quartzite is perhaps the most conspicuous formation in the region. From a distance it appears as a light band emphasized by the nearly black Ely Springs dolomite on top of it. The lower half of the light band is somewhat darker, weathering tan, brownish, or pinkish brown, and is much less homogeneous in color. The quartzite in the upper part is uniformly vitreous, white, or tinged with pink, and is composed of quartz sand grains cemented by quartz that is indistinguishable from the grains except where they are outlined with faint coloring. In the lower quartzite unit there are some intercalated silty or shaly beds, and much of the unit is limonitic or hematitic.

FIGURE 5. Eureka quartzite about 2½ miles north of Ubehebe Peak. Pogonip limestone, Op, below Eureka quartzite, Oe, and Ely Springs dolomite, Oes, above.

A thin section of a random sample of the vitreous quartzite has quartz grains commonly 0.25 to 0.30 millimeter in diameter, falling within a range of 0.015 to 0.55 millimeter. Most of the grains are well-rounded. The original shapes of the grains are faintly outlined by specks, although the quartz cement is in optical continuity with the grains, making a completely interlocking mosaic.

The general aspect of the Eureka quartzite varies little throughout the region. The Eureka has been the most distinctive formation of the area and was mapped with the greatest confidence. The lithology of quartzite beds interstratified in the lowermost part of the Devonian Lost Burro formation at some places is similar to that of the Eureka quartzite, but the quartzite beds of the Lost Burro are only a few feet thick in contrast to the 250 feet of vitreous quartzite in the Eureka formation. The sandy part of the Mississippian Perdido formation, where metamorphosed to quartzite near igneous intrusions, also may resemble Eureka quartzite except for the thinness of the quartzitic unit in the Perdido (only about 50 feet) and its distinctive stratigraphic position. The black Ely Springs dolomite lying on vitreous quartzite at once distinguishes the quartzite as Eureka.

The best exposure for detailed measurement of the Eureka quartzite lies southwest of the area, on the eastern front of a mountain 2½ miles due north of Ubehebe Peak and northwest of The Racetrack playa (see Ubehebe Peak quadrangle and fig. 5). The following section was measured there with a tape:

Ely Springs dolomite.
(Conformable contact.)
Eureka quartzite: *Feet*

2. White vitreous quartzite weathers white or faintly tinted pink or limonitic yellow; in places the weathered surface is sugary. Some cross-bedding is discernible under close inspection; jointing parallel to stratification is rather widely spaced, up to about 5 feet. The contact with the overlying dolomite here is sharp 250
1. Interbedded dark hematitic quartzite, light vitreous quartzite, and some platy quartzite and siltstone. Some of the siltstone is dull gray, contrasting with the reddish gray and light-colored quartzite. Iron-stained quartzite greatly predominates. Cross-bedded 150

400

Contact concealed along line of section. (Float-covered saddle; presumably a shaly part of the Pogonip limestone, about 70 feet thick.)
Pogonip limestone.

Thickness. The stratigraphic thickness of the Eureka quartzite as measured with a tape north of Ubehebe Peak

is 400 feet. Where measured at the southern end of the Andy Hills 6 miles due east it is also about 400 feet thick.

Age and Correlation. No fossils were found in the Eureka quartzite. The silty beds in the lower part should be examined more extensively for them. By lithology and stratigraphic position the formation has been correlated with the Eureka quartzite that crops out so extensively elsewhere in the Great Basin, where it has been designated Middle Ordovician.

The first published correlation of the quartzite in the Death Valley region with the Eureka quartzite was by Spurr (1903, pp. 188, 202), who wrote that F. B. Weeks had observed Eureka quartzite overlying the Pogonip formation south of Shaw Peak in the northern part of the Panamint Range. Spurr tentatively identified the Eureka quartzite also at Pyramid Peak in the Amargosa Range. Ball at a later date did not recognize that much of the quartzite at the northern end of the Panamint Range was Eureka quartzite, although at a locality where it does occur he described it as a "white or pinkish white fine-grained quartzite outcrop on the western side of the playa 4 miles north of Goldbelt Spring" (Ball, 1907, p. 203). He mapped Eureka quartzite in the Grapevine Mountains. Eureka quartzite is one of the few established formations that Hopper (1947, p. 407; fig. 1; pl. 1) distinguished without question at the eastern base of the Panamint Range about 40 miles southeast of Quartz Spring. In the Nopah Range Hazzard (1937, pp. 324-325) measured Eureka quartzite and correlated it with the formation at the type locality as redefined by Kirk (1933). It occurs widely in Nevada. In the Inyo Range the Eureka quartzite is not distinguished from other Ordovician rocks represented on the reconnaissance map (Knopf, 1918, pl. 2); but typical Eureka quartzite associated with Pogonip limestone and Ely Springs dolomite was seen by the writer at the southeastern tip of the range and as far as Mazourka Canyon on the western side of the Inyo Range.

Ely Springs Dolomite (Upper Ordovician)

Name and Occurrence. The Ely Springs dolomite was named originally by Westgate (1932, p. 15) from its exposures in the Ely Springs Range, about 12 miles west of Pioche, Nevada. In the northern Panamint Range the Ely Springs dolomite is bounded by the Eureka quartzite below and by the Hidden Valley dolomite, largely of Silurian age, above.

In the Quartz Spring area the Ely Springs dolomite crops out at the same localities as the Eureka quartzite. It is exposed more continuously southwest of the area, along the eastern front of the mountains north of Ubehebe Peak.

Lithology. The Ely Springs is mostly dolomite, but it contains considerable dark-brown and nearly black nodular chert. At most places chert is restricted to the lower part, but the proportion of chert to dolomite varies notably from place to place. The chert nodules tend to merge, and at exposures that are along the plane of bedding it is evident that they merge into extremely irregular networks parallel to the bedding. From the Eureka quartzite at the base to slightly beyond halfway to the top of the Ely Springs the dolomite is conspicuously dark gray, nearly black. In the upper part it is medium gray to light gray except for one noticeable dark-gray layer. In detail much of the dolomite is mottled somewhat lighter in the dark beds and darker in the medium-gray and light-gray beds. The mottling is so close in some layers that the effect is of wavy bands. Another type of color difference consists of lines of white grains, forming an irregular network through the darker rock. The lines at some places converge into ill-defined whitish blotches. At other places the lines and blotches are of pinkish dolomite. In the lower part of the very dark gray dolomite quartz-lined vugs 1 inch or 2 inches in diameter are common.

A representative specimen of cherty dolomite 10 feet above the contact with Eureka quartzite in thin section shows a trace of quartz grains among the dolomite grains, which commonly are 0.05 to 0.1 millimeter in diameter. The chert consists of a microgranular quartz mosaic (grains commonly 0.005 to 0.01 millimeter), which contains veinlets and scattered rhombohedra of dolomite. There is more quartz, about 3 percent, in a thin section of typical dolomite in the upper unit.

The following section of Ely Springs dolomite, measured with a tape, is taken as the standard for comparison in the region. It is a part of the long section measured on the east front of the mountains about 2½ miles north of Ubehebe Peak, southwest of the Quartz Spring area:

	Feet
Hidden Valley dolomite.	
(Conformable contact.)	
Ely Springs dolomite:	
2. Light-gray dolomite grades downward into about 100 feet of medium-gray dolomite at the base of this unit. Some darker mottling and wavy streaks do not detract from the general effect of being much lighter than the lower unit of the Ely Springs dolomite. About 200 feet from the top a conspicuous dark layer 15 feet thick lies in the light-gray dolomite	380
1. Conspicuous dark-gray dolomite containing lighter mottling, and some white dolomite grains and threadlike lines; near the base there are some quartz-lined vugs about 1 inch to 2 inches in diameter. Abundant flat nodules of chert, from dark brown to black, tend to lie parallel to the bedding, starting 30 feet from the base, and diminishing in proportion to the dolomite up to a level about 250 feet above the base of the formation. Brachiopods and corals	560
(Conformable contact.)	940
Eureka quartzite.	

The following section was measured at the southern end of the central long ridge of the Andy Hills on the east side of Hidden Valley:

	Feet
Hidden Valley dolomite.	
(Conformable contact.)	
Ely Springs dolomite:	
2(b). No outcrops through talus on the upper 65 feet of the top unit. Thin transitional beds of light and dark dolomite mottled in streaks parallel to the bedding; some lumpy chert also tends to be parallel to the bedding	90
2(a). Light-gray dolomite, grading into medium gray especially toward the bottom, where there is light-colored mottling about 1 inch in diameter	250
1(b). Dark smoke-gray or black dolomite contains network and clusters of coarser grains of very light-gray and pink dolomite grains; no chert	75
1(a). Dark-gray and black dolomite contains abundant chert, which becomes prominent about 25 feet above base. The chert is dark gray, weathering dark brown, and forms irregular plates that appear as brown streaks and lenses in outcrops across the bedding. Small fragments of fossils are in the basal 25 feet of dolomite. Gray dolomitic sandstone lies on the Eureka quartzite at the base	325
(Conformable contact.)	740
Eureka quartzite.	

		ROBERTS MOUNTAINS REGION, NEVADA (Merriam, 1942)	QUARTZ SPRING REGION, CALIF. (This report)	NOPAH RANGE, CALIF. (Hazzard, 1937)
CARBONIFEROUS	Pennsylvanian	*(Discontinuity)* Diamond Peak beds *(greater part unrecognized)*	*(Eroded)* Tihvipah limestone 200± ft.	Bird Springs(?) formation 780+ ft.
			Rest Spring shale[1] 310± ft.	
	Mississippian		Perdida formation 610± ft.	*(Break in section)* Monte Cristo(?) limestone 987± ft.
			Tin Mountain limestone 475 ft.	*(Unconformity)*
DEVONIAN	Upper	Devils Gate formation 2,065 ft.	Last Burro formation 1,525 ft.	Stewart Valley limestone[2] 1,180 ft.
	Middle	Nevada formation *(restricted)* 2,400 ft.		*(Possible unconformity)* Sultan dolomite 890± ft.
	Lower			*(Unconformity)* *(Missing)*
SILURIAN		Lone Mountain formation *(restricted)* 2,200 ft.	Hidden Valley dolomite 1,365 ft.	Silurian(?) dolomite 335 ft.
		Roberts Mountains formation 1,900 ft.		
ORDOVICIAN	Upper	Hanson Creek formation 560 ft.	Ely Springs dolomite 940 ft.	Ely Springs(?) dolomite 800 ft.
	Middle	Eureka quartzite 500 ft.	Eureka quartzite 400 ft.	Eureka quartzite 265 ft.
	Lower	*(Discontinuity)* Paganip group, lower part *(undifferentiated Lower Ordovician and Upper Cambrian)*	Paganip limestone 1,440 ft.	Paganip(?) dolomite 1,040± ft.
CAMBRIAN	Upper		Nopah formation 1,600 ft.	Nopah formation 1,740± ft.
	Middle		Racetrack dolomite[3] 1,900± ft.	Cornfield Springs formation 2,975 ft.

FIGURE 6. Tentative correlation of the formations in the Quartz Spring area with the formations in the Roberts Mountains region and the Nopah Range.

[1] Pennsylvanian(?).
[2] The base of the Stewart Valley limestone is shown not at the lower boundary of the Mississippian, where it was originally drawn by Hazzard (1937), but as herein correlated with the upper part of the Lost Burro formation. A revision by Hazzard (1951) drops "Stewart Valley limestone" and extends the Monte Cristo limestone downward and the Sultan limestone upward to an unconformity between the Carboniferous and the Devonian systems.
[3] Middle(?) Cambrian.

Thickness. The stratigraphic thickness of the Ely Springs dolomite in the local standard section about 2½ miles north of Ubehebe Peak is 940 feet. In another section measured on the same mountain front, about a third of a mile north of the first section, where the upper unit is 235 feet thick and the lower unit is 580 feet thick, the total thickness is 815 feet. About 6 miles east of these sections, in the Andy Hills, the stratigraphic thickness of the Ely Springs dolomite is 740 feet.

Age and Correlation. A few fossils from the Ely Springs dolomite in this region have been identified. Those listed below, collected by Miller W. Ellis for the Geological Survey, were identified by G. Arthur Cooper (written communication 1949). The following fossils are from the base of the dark-gray dolomite at the locality 2½ miles north of Ubehebe Peak:

E-19 Streptelasma sp.
Resserella sp.
Dinorthis aff. D. subquadrata (Hall)
Rhynchotrema aff. R. capax (Conrad)

and from a place higher in the same unit:

E-20 Streptelasma sp.
Halysites sp.
Rhynchotrema cf. R. argenturbicum (White)
Zygospira cf. Z. modestus (Say)

The fauna is consistent with the Late Ordovician age of the original Ely Springs dolomite.

On the basis of lithology and of stratigraphic position above the Eureka quartzite the formation can be correlated with the Ely Springs (?) dolomite of the Nopah Range (Hazzard, 1937, pp. 325-326), which has been correlated tentatively with the original Ely Springs dolomite in the Pioche district, Nevada (Westgate, 1932, pp. 15-16). A similar dark-gray dolomite, though unnamed, according to Hazzard (1937, p. 326), occurs at several localities in the southern Great Basin. Ely Springs dolomite, associated with Eureka quartzite, was seen by the writer at the southeastern end of the Inyo Range. At the eastern base of the Panamint Range, Hopper mapped Ely Springs (?) dolomite and tentatively correlated it with the Ely Springs dolomite at Pioche (Hopper, 1947, p. 407, pl. 1).

Hidden Valley Dolomite (Silurian and Lower Devonian)

Name and Occurrence. The Hidden Valley dolomite is here named for the good exposure on the eastern side of Hidden Valley (fig. 1), about 3 miles east-southeast from bench mark 5980 (pl. 1) near Lost Burro Gap. The best exposure of the formation, however, is not in Hidden Valley but at the type locality about 6½ miles westward. The type locality of the Hidden Valley dolomite is on the eastern flank of a mountain about 2½ miles north of Ubehebe Peak, and about three-fourths of a mile west of the road in Racetrack Valley. The formation is limited below by the Ely Springs dolomite and above by the Lost Burro formation.

Within the mapped area the entire section of the Hidden Valley dolomite occurs in the Andy Hills on the eastern side of Hidden Valley. A more accessible exposure, bearing conspicuous silicified fossils, is along the Hidden Valley road south of Lost Burro Gap. Here the section is incomplete but is representative of the formation. The Hidden Valley dolomite crops out also along the top of the ridge east of Quartz Spring, and on Whitetop Mountain (see pl. 1).

The topographic expression of the Hidden Valley dolomite is like that of the great thickness of dolomite and limestone above and below it; all these units tend to make steep rather blocky slopes, slightly more prominent at cherty zones.

Lithology. The Hidden Valley rather uniformly consists of dolomite but contains considerable nodular chert near the bottom, and a little silt and sand near the top. The color of the dolomite in the lowest and highest units is a medium gray that weathers light olive gray or yellowish gray; in the middle it is very light gray or creamy. At most places it lacks very dark beds except on Whitetop Mountain on the main crest of the Panamint Range due east of Rest Spring, where the basal beds containing Silurian fossils are nearly black. The chert is light gray or light brown and weathers to a darker brown. It forms nodules, which tend to join into coarsely branching masses or irregular beds. Fossils are abundant in the lower part and scarce near the top of the formation.

In samples of the lowest unit, as seen in thin section, the quartz-free dolomite forms grains commonly about 0.1 millimeter in diameter. The creamy dolomite of the middle unit is somewhat coarser grained and, where examined, is free of quartz. The top unit, which in places has a few thin obviously silty and sandy beds, is fine-grained. In a thin section of a typical specimen the dolomite contains roughly 5 percent quartz grains about 0.05 millimeter in diameter.

The section measured with a tape at the type locality 2½ miles north of Ubehebe Peak follows:

Lost Burro formation.
(Conformable contact.)
Hidden Valley dolomite:

	Feet
3. Medium dark gray, fine-grained dolomite; lacks sandy or cherty beds, except for a 15-foot zone of brownish-weathering silty beds at the base of the unit	200
2. Massive, very light gray (nearly white) dolomite, weathering creamy; becomes slightly darker and in places faintly mottled with darker gray, in upper part. The only trace of fossils was seen near the base of the unit, where the cellular structure of favositoids survived the rather coarse crystallization of the dolomite	730
1. Medium-gray and medium light gray dolomite, weathering light olive gray, contains conspicuous chert. The basal beds are banded gray and lighter gray from a fraction of an inch to several inches thick, having rather wavy contacts. The chert is light gray to light brown and forms nodules that in section are round or oblate, if not more irregular; in places the nodules join to form chert beds 2 to 4 inches thick. The proportion of chert decreases above a zone 250 feet from the base of the formation. Abundant fossils, including conspicuous *Halysites catenularia*, about 325 feet above the base	435
	1,365

(Conformable contact.)
Ely Springs dolomite.

Near the southern end of the central ridge in the Andy Hills the following section of the Hidden Valley dolomite was measured:

Lost Burro formation.
(Conformable contact.)
Hidden Valley dolomite:

	Feet
3(b). Medium dark gray dolomite, weathering light olive gray; thin-bedded; lower 50 feet fossiliferous (*Spirifer kobehana* zone of Merriam)	65
3(a). Medium-gray dolomite weathers grayish buff or medium gray; thin-bedded. About 5 feet of brown-	

		Feet
	weathering quartzite occurs 35 feet above the base of the unit	450
2.	Very light gray, nearly white, rather coarse-grained dolomite weathers light creamy buff; no discernible bedding; only traces of fossils such as the honeycomb structure of favositoids	635
1(b).	Brownish-gray dolomite, weathering yellowish brown, contains light-gray chert. Fossils	125
1(a).	Medium-gray dolomite, weathering medium buff gray, contains abundant dark-gray or dark-brown chert, constituting up to a half but more usually a third of the rock. The chert forms irregular nodules, many of which appear like branching somewhat flat masses or irregular sheets 1 inch to 2 inches thick, in general parallel to the bedding. Many well-preserved fossils including abundant *Halysites*	90
		1,365

(Conformable contact.)
Ely Springs dolomite.

The poorly defined threefold nature of the formation—that is, medium-gray dolomite containing much chert in the lower part, then creamy chert-free coarser-grained dolomite, overlain by somewhat darker thinner-bedded fine-grained dolomite—is persistent through the area.

Other chert-bearing dolomites in the Paleozoic section, such as the Ely Springs dolomite, could be mistaken for the Hidden Valley dolomite, especially if they are sufficiently metamorphosed to obscure characteristic colors. The dark-gray Tin Mountain limestone has considerable chert but the carbonate rock is distinctly limestone. In isolated outcrops where stratigraphic relationships are not known, the upper part of the Hidden Valley dolomite could be mistaken for the massive dolomite in the Pogonip limestone, upper Ely Springs, and parts of the Lost Burro formation.

Thickness. At the type locality on the west side of Racetrack Valley and at the place in the Andy Hills on the eastern side of Hidden Valley, 6 miles from the first locality, the thickness of the Hidden Valley dolomite is 1,365 feet.

Age. The lower fossiliferous part of the Hidden Valley dolomite (unit 1) is Silurian, probably equivalent in age to the top of the Clinton group in the Niagaran series [1]. Near the upper boundary of the formation (unit 3b), however, a fossiliferous zone 50 feet thick is Lower Devonian. Certain diagnostic fossils from the Silurian part were identified by the writer early in the work. *Halysites catenularia* (Linnaeus) and *H. microporus* (Whitfield), typical of the Niagaran series, are abundant in this zone at widely spaced localities. *Favosites* cf. *F. niagarensis* Hall of Niagaran age, though much less abundant, is also characteristic of the Hidden Valley dolomite. A different assemblage, containing *Porpites porpita* (Linnaeus), a good middle Silurian button coral, was found on Whitetop Mountain.

Within unit 1 of the Hidden Valley dolomite at the type locality, the small rather globular *Favosites* occurs in the basal beds and upwards; higher it is associated with horn corals and a few brachiopods. At 330 feet above the base the *Favosites* is the commoner discoidal form 1 to 2 feet in diameter, and it is associated with a syringoporoid coral. Abundant *Halysites* occur in a highly fossiliferous zone about 15 feet thick starting 325 feet above the base of the formation. Fossils continue to occur sporadically to the top of unit 1.

The well-preserved specimens of *Porpites porpita* were found near the base of the formation on Whitetop Mountain (see pl. 1), where it lacks the usually characteristic chert. Comparison with three good specimens [2] of *P. porpita* from Gotland, the type locality of the species, suggested to the writer that the species from Sweden and California are possibly identical (McAllister, 1940, pp. 1984-1985). The morphologic characters of the specimens of *P. porpita* from the Panamint Range vary widely, however, and include the features shown by *P. rotuloides* (Hall) and *P. michiganensis* (Bassler). The stratigraphic range of *P. porpita*—including the above as synonyms—when correlated according to the Silurian chart sponsored by the National Research Council (Swartz, et al., 1942, chart 3) is essentially the same in North America (upper part of the Clinton and in the Manistique dolomite) as it is in Europe (upper part of the Llandoverian series and the lower part of the Wenlock series). The species, therefore, is a good marker of the middle part of the Niagaran series.

Other specimens of button corals collected much later at the western foot of Whitetop Mountain, although from a fault zone, were believed to be from the same zone of *P. porpita*. A report on the collections from this locality (U-651) by Jean M. Berdan (written communication, 1950) of the U. S. Geological Survey, in consultation with Edwin Kirk, Helen Duncan, and G. A. Cooper, states that the many small button corals "superficially appear to be close to the Devonian genus *Microcyclus*, as they have a well-defined fossula, a structure reported to be lacking in the Silurian button corals. However, these specimens have acanthine septa, which are characteristic of *Porpites* and other Silurian 'acanthocyclid' [3] corals and may represent a new genus.[4] This collection also contains a small *Halysites* unlike those in the other collections [from north of Ubehebe Peak], bryozoan fragments, a few brachiopods of Silurian affinities, and the pygidium of a bumastid trilobite."

Fossils from the lowest unit of the Hidden Valley dolomite nearly a mile south of the type locality were collected by M. W. Ellis for the U. S. Geological Survey. G. Arthur Cooper (written communication, 1949) reported the following about them:

"E18.—Corals, mostly unidentifiable. The collection contains *Halysites* with numerous cup corals, possibly including *Amplexus*

[1] Clinton group and Niagaran series are used in Chart No. 3—Correlation of the Silurian formations of North America (Swartz et al., 1942), sponsored by the National Research Council. The use of the terms here does not indicate any change in the nomenclature of the U. S. Geological Survey, which considers the Clinton as a formation and the Niagara as a group.

[2] Contributed by H. G. Schenck to the Stanford University collection.

[3] "The term 'acanthocyclid' is used here to indicate structural relationship with the group of coral genera Hill included in the family Acanthocyclidae. As the name of the type genus was subsequently found to be preoccupied and as no new family has yet been established for these corals, it has been necessary to employ invalid terminology."

[4] According to Helen Duncan, who has recently studied a large suite of topotypes of *Porpites porpita* in the collections of the U. S. National Museum: "All the Gotlandian specimens examined exhibit a somewhat aborted cardinal septum, a feature that apparently has been overlooked or ignored by previous investigators. It is true that the effect of this short major septum on the striking radial septal plan is scarcely noticeable in the calyx; but in specimens ground down to the basal disc, the gap produced by the shortening of the cardinal septum is rather conspicuous and in my opinion corresponds to the cardinal fossula commonly developed in other rugose corals. It appears that the genus *Porpites* should be revised to include species with fossulae. Under the circumstances I see no objection to referring the specimens from the Silurian part of the Hidden Valley dolomite to *Porpites*; however, these specimens have conspicuous cardinal fossulae, as well as pinnately arranged septa, and pits marking the position of the alar fossulae, and it seems to me that these characters are sufficiently diagnostic to distinguish the California species from *P. porpita*."

among others. One good Silurian index present is *Favosites* like *F. gothlandica*. Also present are corals resembling *Ptychophyllum*. The sponge *Hindia* is present."

Collections submitted later from the type locality and one (U-651) from the base of Whitetop Mountain were described by J. M. Berdan (written communication, 1950), in consultation with Edwin Kirk, Helen Duncan, and G. A. Cooper, as follows:

"Collections U-137-A and U-137-E+20 consist of several kinds of corals, with the genus *Halysites* predominating. Most of these specimens are too poorly preserved for specific identification, but even if the material were well preserved, it is doubtful that specific identification would be possible, as little work has been done on the Silurian corals of the Great Basin province and many of these forms probably are undescribed species. In the case of the species of *Halysites*, affinities have been indicated with varieties described by Lambe (Geol. Surv. Canada, Contrib. Canadian Paleontology, vol. 4, pt. 1, 1899) from Canada, but it should be recognized that this is based entirely on the size of the corallites without reference to the internal structure and is extremely tentative. Collection U-137-F+ contains, in addition to the corals, large crinoid columnals which have pores through the walls and eccentric lumens, but otherwise appears to represent the same fauna as the two above collections."

* * * * *

"U-137-A. *Favosites* sp. with large corallites, *Favosites* sp. with smaller corallites, *Heliolites* sp. with large corallites, *Heliolites* sp. with smaller corallites, cyathophyllid horn coral, badly decorticated.

"U-137-E+20. *Halysites (Cystihalysites)* sp. aff. *H. Catenularia* var. *simplex* Lambe, *Halysites (Halysites)* sp. of medium size, *Halysites* sp. aff. *H. catenularia* var. *micropora* Whitfield, zaphrentid horn coral, cyathophyllid horn coral, *Alveolites* ? sp., coral superficially resembling *Cladopora*, and a phaceloid rugose coral.

"U-651 [Locality at western base of Whitetop Mountain]. *Tryplasma* sp., zaphrentid horn coral (contorted corallum); 'acanthocyclid' coral with fossulae, *Porpites* aff. *P. porpita: Halysites* sp., not same as those of other collections; bryozoan fragments; *Atrypa* cf. *A. reticularis: Parmorthis* sp.; *Rhipidomella* sp.; pygidium of bumastid trilobite."

Fossils of the uppermost unit (Lower Devonian) of the Hidden Valley dolomite (unit 3b), from a zone 50 feet thick lying 15 to 65 feet below the top of the formation in the Andy Hills (see pl. 1) were identified and correlated by G. Arthur Cooper (written communication, 1949) as follows:

U-436a Favosites sp.
Papiliophyllum elegantulum Stumm
Breviphyllum lonensis (Stumm)
Breviphrentis invaginatus (Stumm)
Unidentifiable cup corals
Branching Cladopora
Heliolites sp.
Acrospirifer kobehana (Merriam)
Meristella robertsensis Merriam
Platyceras sp.

"This collection is Lower Devonian in age, the Oriskany portion of the Nevada limestone of Merriam."

The fauna contains some of the distinctive forms of the *Spirifer kobehana* zone at the base of Merriam's restricted Nevada limestone (Merriam, 1940, pp. 52-53, fig. 7, tables 3 and 4). In addition to *Acrospirifer kobehana* (Merriam), it has the diagnostic species *Papiliophyllum elegantulum* and *Meristella robertsensis*. C. W. Merriam later collected from unit 3(b) in the Andy Hills and found in some abundance a large *Spirifer* of the *Spirifer arenosa* (Conrad) group (written communication, 1950), confirming the Oriskany age.

The Silurian-Devonian boundary thus falls within the uppermost part of the Hidden Valley dolomite. The persistent lithologic change is above the Lower Devonian fossils, in contrast to the minor variations in lithology below the fossiliferous beds. These minor variations are poorly defined and have not been correlated from place to place. The distinctive formational boundary has been readily mapped over a broad area.

Correlation. Rocks containing Niagaran fossils long have been known in the Great Basin. The Lone Mountain formation, named by Hague in 1883 in the Eureka region, contains Niagaran fossils in the upper part, and Upper Ordovician fossils in the lower part. Spurr (1903, p. 86) in the Hot Creek Range, Nevada, identified fossils probably of Niagaran age, including "*Halysites catenulatus*, large variety" and "*H. catenulatus*, small variety" in the Lone Mountain. He noted the occurrence of "Upper Silurian" rocks above the Eureka quartzite near Cottonwood Canyon in the northern Panamint Range, without describing the rock, so that he may have meant the Ely Springs rather than the Hidden Valley dolomite. Spurr's reference to the Silurian is apt to be confusing because he follows an older usage and includes Ordovician in Silurian, except when he quotes other geologists. The Lone Mountain formation in the original sense was used by Ball to include strata of Trenton and Niagaran age—that is, the Ely Springs as well as the Hidden Valley. From the descriptions of occurrences in the Amargosa Range it is impossible to judge whether Ball (1907, p. 165) recognized the equivalent of the Hidden Valley. No Lone Mountain was described in the Panamint Range.

Later publications on the Great Basin describe Silurian rocks without a name, such as in the Pioche region (Westgate and Knopf, 1932, p. 16), the Spring Mountains region (Nolan, 1929, p. 462), the Nopah Range (Hazzard, 1937, p. 326), and questionably, south of Pinto Peak in the Panamint Range, where they were grouped with Devonian rocks (Hopper, 1947, p. 408). These Silurian rocks in the Pioche district were correlated by Kirk (Westgate and Knopf, 1932, p. 16) with the Fusselman limestone of the El Paso region and New Mexico, as well as with the Niagaran part of the Lone Mountain limestone.

The Lone Mountain formation in the Roberts Mountains region was restricted by Merriam (1940, p. 13) to the uppermost part of the original Lone Mountain limestone, which "is largely dolomitic and barren of determinable fossils with the exception of a single specimen of a poorly preserved *?Syringopora* found within a few feet of the base at Lone Mountain. The determination of age rests therefore on position of the formation between the fossil-bearing Roberts Mountains formation and the Nevada formation." Merriam's restricted Lone Mountain formation is approximately equivalent to the middle and some of the upper part of the Hidden Valley dolomite (see fig. 6), and his Roberts Mountains formation (the middle unit of the original Lone Mountain limestone) is equivalent to the lower part of the Hidden Valley dolomite. The lowest unit in the original Lone Mountain, of late Ordovician age, was called Hanson Creek formation by Merriam, and it is equivalent to the Ely Springs dolomite as used in the Panamint region.

The uppermost part of the Hidden Valley dolomite (unit 3(b)) corresponds in age to the lowermost part of the Nevada formation as defined by Merriam (1940, pp. 13-14). The *Spirifer kobehana* zone, which is the first persistent faunal zone of early Devonian age in the Roberts Mountains region, lies 100 to 150 feet above the base of the Nevada formation at Lone Mountain (Mer-

FIGURE 7. Lost Burro formation at type locality. Western side of Lost Burro Gap at southern end. Lost Burro formation, Dlb, is above Hidden Valley dolomite, Shv, and below Tin Mountain limestone, Ctm.

riam, 1940, p. 52). The base of the same faunal zone in the Quartz Spring area, where the zone is 50 feet thick, lies 65 feet below the top of the Hidden Valley dolomite.

Lost Burro Formation (Middle (?) and Upper Devonian)

Name and Occurrence. The Lost Burro formation is here named for exposures at Lost Burro Gap, through which the road passes from Racetrack Valley to Hidden Valley. The type locality is on the western side of the gap at the southern entrance; it extends from the Hidden Valley dolomite at the base of the slope to the Tin Mountain limestone near the top (fig. 7).

The Lost Burro formation is exposed extensively, although not continuously from bottom to top, at other places in the Quartz Spring area. The best outcrops are in Lost Burro Gap, the Andy Hills, East Crest, and along the flanks of West Crest. The formation is widespread also in the surrounding region between Death Valley and Saline Valley. It tends to form conspicuous cliffs, and high steps in canyons.

Lithology. The general appearance of the Lost Burro formation is of a very light gray dolomite prominently striped with nearly black limestone and dolomite. The color alone is not a reliable indicator of whether the rock is limestone or dolomite, but the limestone where not metamorphosed is dark. The lower part is entirely dolomite. Sandy beds that weather brownish gray mark the base of the formation. At some places the sand forms layers of vitreous quartzite 2 or 3 feet thick, which weather into massive blocks but show thin bedding and crossbedding. Throughout the rest of the formation up to the quartzite and sandy shale at the top, the quantity of sand in the rocks is negligible. Midway in the section conspicuous black limestone beds consist of masses of stromatoporoids, of which the peculiar concentric cellular structure is sufficiently persistent to be considered a lithologic characteristic of that part of the formation. In the same way spaghettilike outlines of masses of cladoporoids in several beds can be considered another characteristic of the lithology. Within the region the combination of these two structures of organic origin occurs in none of the other formations and is an excellent indicator of the Lost Burro formation.

The following section was measured by tape at the type locality of the Lost Burro formation, south of Lost Burro Gap (fig. 7):

Tin Mountain limestone.
(Conformable contact.)

Lost Burro formation:	Feet
5. Very light gray sandy dolomite and quartzite; upper part weathers brown; uppermost part, somewhat shaly, weathers slightly pinkish brown; (contains excellent *Cyrtospirifer* in outcrops at lower end of Lost Burro Gap)	35
4. Very light gray dolomite and some interstratified medium gray dolomite, producing a banded effect similar to the underlying unit but in general much lighter gray	335
3. Dark-gray dolomite mottled by white forms resembling broken spaghetti; beds of stromatoporoids in very dark gray limestone or dolomite, interbedded with light- and dark-gray dolomite and limestone	530
2. Light-gray dolomite mottled and streaked with cream-colored dolomite; dark-gray or black dolomite; dark-gray dolomite mottled with lighter gray	470
1. Light-gray sandy dolomite, weathering mouse gray, containing abundant chert in very irregular nodules; sand weathers dark brown, making rough surface, and in some places forms quartzite	155
(Conformable contact.)	1,525

Hidden Valley dolomite.

The lower units, 1, 2, and 3, of the following section were measured along the central north-trending ridge of the Andy Hills, and the upper units, 4 and 5, were measured up the southern slope of the hills north of the Andy Hills (see pl. 1):

Tin Mountain formation.
(Conformable contact.)

Lost Burro formation:	Feet
5. Very light gray sandy dolomite grading into quartzite; platy brown-weathering calcareous sandstone at top; fossiliferous	40
4. Very light gray dolomite, and some interbedded medium gray dolomite (Gap in measured section, where covered by alluvium that may conceal complicating structures)	295
3. Dark-gray or black dolomite, some a mass of stromatoporoids, and some mottled by spaghettilike forms; medium-gray and light-gray dolomite interstratified with the darker, which is predominant (top of this unit covered by alluvium)	1,400?
2. Medium-gray dolomite grading into layers of lighter or somewhat darker dolomite; lacking stromatoporoids and spaghettilike markings; basal 150 feet, coarse-grained light-gray dolomite marked by indistinct wavy bands roughly parallel to the bedding	260
1. Medium-gray sandy dolomite; 20 feet of massive very light gray sandstone 175 feet above base, separated by 15 feet of mud-stone from underlying dark-weathering chert zone 35 feet thick	250
(Conformable contact.)	2,245?

Hidden Valley dolomite.

Stratigraphic details at the boundary between the Lost Burro formation and the Hidden Valley dolomite in the Andy Hills are listed below. The numbers correspond to units in the complete sections on page 15 (Hidden Valley dolomite) and page 19 (Lost Burro formation).

Lost Burro formation:	Feet
1. Medium-gray dolomite, more or less sandy in lenses and in poorly defined discontinuous beds; a few inconspicuous pebbles of light-gray dolomite in some of the sandy layers	55
Very light gray sandstone; a little dolomite cement in massive layer	20
Light-gray mudstone (nonfissile shale)	15
Gray chert, weathering brownish black, in medium light gray dolomite; less chert in sandier base	35
Medium-gray dolomite containing brownish-weathering sand and silt in poorly defined lenses and beds, and outlining conspicuous sinuous branching forms	125
	250
Conformable contact.	
Hidden Valley dolomite:	
3(b). Medium dark gray dolomite, weathering light olive gray; thin-bedded	15
Same medium dark gray dolomite, containing abundant silicified fossils; *Spirifer kobehana* zone	50
	65

Thickness. At the type locality on the western side of the southern entrance to Lost Burro Gap the stratigraphic thickness of the Lost Burro formation is 1,525 feet. The total thickness of the section measured in the Andy Hills is questionable, owing to structural uncertainties in units 3 and 4 and under the alluvium between them.

Age and Correlation. The age of the Lost Burro formation is Late Devonian and in part probably Middle Devonian. As shown by excellently preserved brachiopods, the sandy beds within 35 feet of the top of the formation correspond to the Conneaut group in the upper part of the Cassadaga stage of the Upper Devonian (see Cooper et al., 1942, chart 4). There is little definitive faunal evidence for assigning much of the formation to the Middle Devonian, but abundant stromatoporoids and cladoporalike forms suggest that it is correlative with the Great Basin Middle Devonian. This age determination is supported by the stratigraphic position of the formation, without obvious depositional breaks, between Upper Devonian and Lower Devonian fossiliferous zones.

Fossils collected from the sandy uppermost 35 feet of the Lost Burro formation, at the lower end of Lost Burro Gap (fig. 8), were identified and correlated by G. Arthur Cooper (written communication, 1949) as follows:

U-183 Cyrtospirifer cf. C. monticola (Haynes)
C. cf. C. disjunctus (Sowerby)
Tylothyris? cf. T.? raymondi Haynes
"Camarotoechia" aff. "C." duplicata (Hall)
Cleiothyridina cf. C. devonica Raymond
Productella sp.

These ". . . are clearly related to Three Forks shale species. The species, however, of '*Camarotoechia*' cf. '*C.*' *duplicata* indicates correlation with the upper part of the Cassadaga stage in New York." This confirms the opinion earlier expressed in the field by C. W. Merriam (1947) that the fauna was of Three Forks age and that much of the Lost Burro formation was similar to the Devils Gate formation in Nevada.

Specimens (U-133 and U-133a) from the middle of the formation, starting 475 feet below the top and continuing 225 feet lower, were too poorly preserved to identify (G. Arthur Cooper, written communication, 1949) other than as "unidentifiable Bryozoa and corals; *Atrypa* sp.; branching *Cladopora*; silicified and unidentifiable *Stromatopora*."

The upper part of the Lost Burro formation can be correlated with the Sultan limestone as established by Hewett (1931, pp. 13-16) in the Goodsprings quadrangle, but the lower part, which extends well below the stromatoporoid beds similar to the basal Ironside member of the Sultan limestone, may continue into the equivalent of the uppermost part of the Goodsprings dolomite. The lower part of the Lost Burro formation seems equivalent to the Sultan dolomite as redefined by Hazzard (1937, pp. 328-331) for the Nopah Range, but the sandy top of the Lost Burro formation is lithologically similar to the lower part of Hazzard's Stewart Valley limestone (see fig. 6). The designation of the lowest member of the Stewart Valley limestone as Mississippian is on the meager faunal basis of one collection (No. P.B. G-5) containing "Corals and *Stromatopora* possibly of Mississippian age." The Lost Burro formation also contains corals and stromatoporoids, which though of undetermined age lie under the diagnostic *Cyrtospirifer* zone of Late Devonian age. The sandy base of the Lost Burro formation is similar to the base of the redefined Sultan dolomite, which Hazzard placed lower than that of the original Sultan limestone. But Hazzard in 1951 revised the Devonian and Carboniferous sections in the Nopah Range by dropping Stewart Valley limestone and applying Hewett's terms for subdivisions of the Sultan limestone and the Monte Cristo limestone. To Hewett's members of the Sultan limestone, however, Hazzard added "Basal member," 230 feet thick. Thus, as nearly as can be determined from an abstract, the Lost Burro formation and the Sultan limestone in the Nopah Range become more nearly correlative.

FIGURE 8. Contact of Lost Burro formation, Dlb, with overlying Tin Mountain limestone, Ctm. Eastern side of Lost Burro Gap near northern end. *Cyrtospirifer* zone in brown sandstone shows from lower left to top of view.

In east-central Nevada the Devils Gate formation in the Roberts Mountains region (Merriam, 1940, pp. 16-17) appears equivalent to the upper part of the Lost Burro formation; and the restricted Nevada formation—all but the basal part—apparently corresponds to the remainder of the Lost Burro. This correlation makes the Lost Burro formation approximately equivalent to all but the base of the original Nevada limestone. Even if nearly the entire Devonian succession falls thus into a single formational division, the Lost Burro formation is nevertheless the appropriate lithologic unit for mapping in the Quartz Spring region. This does not force the Devonian rocks here into a single time-rock unit; the number of time-rock units within it depends on the number of diagnostic faunas that can be correlated with those in established time-rock units, or that are suitable bases for new ones. In the Pioche district the Silverhorn dolomite and part of the West Range limestone (Westgate and Knopf, 1932, pp. 16-19) in lithology and age seem at least roughly equivalent to the Lost Burro formation.

Tin Mountain Limestone (Mississippian)

Name and Occurrence. The Tin Mountain limestone is here named for the northernmost peak in the Panamint Range (see Ballarat quadrangle map), where it forms prominent cliffs near the top on the eastern and southern sides of the mountain. As the top of Tin Mountain is somewhat inaccessible, the type locality of the Tin Mountain limestone is designated as the southern slope of the hills about 2½ miles southeast of Quartz Spring and about 3,000 feet north of the road to Rest Spring, where the entire sequence is exposed from the underlying Lost Burro formation to the overlying Perdido formation. A still more accessible exposure, which lacks, however, the upper contact of the formation, is at the northern end of Lost Burro Gap. The Tin Mountain limestone crops out widely and conspicuously at many places throughout the Quartz Spring area. It forms steep-walled canyons and cliffs on mountainsides more readily than any of the other formations (fig. 9).

Lithology. The lower part of the Tin Mountain limestone consists of dark-gray limestone in beds 2 to 6 inches thick, separated by much thinner beds of light brownish gray to pale-red shale. The upper part consists of medium-gray limestone that from a distance appears to be a single massive layer, but actually the limestone is in beds that range in thickness from a few inches to 2 feet (figs. 8 and 9). In some places mere traces of the shale remain as pale-red partings. Some beds of limestone are made up of fragmented crinoid stems. An abundance of *Syringopora* is distinctive; favositoids and horn corals are common. Both the lower and upper parts of the formation contain a little dark-gray chert, which weathers dusky brown or dark yellowish brown, in elongate nodules.

Features that distinguish the Tin Mountain limestone from the other formations of the region are the persistence of dark limestone, the thin pale-red shaly beds and partings, chert only in nodules, and the abundance of *Syringopora*. The only dark limestone stratigraphically lower—the limestone in the Lost Burro formation—is thinner, interstratified with dolomite, and is marked by stromatoporoid and cladoporoid structures. Stratigraphically higher, the only massive dark limestone is in the Perdido formation, which though gradational from the Tin Moun-

tain, is distinguished by beds of chert and thick layers of shale and siltstone interbedded with the limestone. The distinctiveness of the Tin Mountain limestone makes it an excellent marker.

The following section was measured at the type locality:

Perdido formation.
(Conformable contact.)

Tin Mountain limestone:	Feet
2. Medium-gray limestone in beds a few inches to 2 feet thick but resisting as a unit to form cliffs; pale-red partings are faint; some nodules of dark-gray chert; poorly preserved horn corals and segments of crinoid stems scattered throughout	200
1. Medium dark gray limestone in beds 2 to 6 inches thick; thinner beds of calcareous shale, light brownish gray to pale red; some nodules of dark-gray chert; weathering dusky brown or dark yellowish brown; locally somewhat concealed by rubble from same unit	275
	475

(Conformable contact.)
Lost Burro formation.

West of the Quartz Spring area another section showing the two characteristic units of the Tin Mountain limestone was measured in the canyon draining past the Ubehebe mine (see fig. 1) westward into Saline Valley, at a prominent constriction in the canyon about a mile in a straight line N. 70° W. of the mine and about 7 miles in a straight line due west of the type locality of the Tin Mountain limestone.

Perdido formation.

Tin Mountain limestone:	Feet
2. Dark bluish gray limestone, containing dark-weathering chert lenses 2 to 12 inches long and 1 inch to 4 inches thick; although appearing massive, is composed of beds 6 inches to 2 feet thick	265
1. Beds of dark-gray or light brownish gray limestone as much as 6 inches thick, separated by pale-red shaly limestone beds that become thinner and redder-gray upward where they are mere red-tinged partings in the base of the overlying unit; somewhat crenulated	160
	425

Lost Burro formation.

Thickness. At the type locality, about 2½ miles straight southeast of Quartz Spring, the thickness of the Tin Mountain limestone is 475 feet, and about 7 miles due west of that locality it is 425 feet. The true thickness of the lower incompetent unit is modified by crenulation and boudinage structure. A factor of uncertainty in comparing measurements of the upper unit is the gradational nature of the contact with the overlying Perdido formation.

Age and Correlation. The age of the Tin Mountain limestone, according to a qualified determination of the poorly preserved fossils, is early Mississippian. The alternate possibility that the Tin Mountain limestone is older than Mississippian has been favored by C. W. Merriam (oral communication in the field, 1947; written communication, 1950). Two collections of fossils, U-183tm from the excellent exposure at the lower end of Los Burro Gap and U-200 from the top of the mountain about 1,000 feet south of bench mark 5980, that is 8,000 feet south of the first locality, were submitted to the U. S. Geological Survey. James Steele Williams' report (written communication, 1949) on the collections is quoted in full below:

"Two collections are described as being from this formation, U-200 and U-183tm. Collection U-183tm is composed of corals, crinoid columnals, and several incomplete specimens of two species of brachiopods. The corals were studied by Miss Helen M. Duncan, who reports as follows:

" 'This collection contains several specimens of *Syringopora* of the *S. aculeata* and *S. surcularia* types and several much-weathered and silicified examples of small horn corals. One of the specimens shows a zaphrentoid arrangement of septa in early ephebic stage, but the lot as a whole is too poorly preserved for identification.

" 'The Syringoporas in this collection look like species that are widely distributed in the lower Mississippian rocks of western United States. In the West, *Syringopora* has been reported from the Devonian in a few areas, mainly in the southern part of the Great Basin region. Except in a few places such as the Eureka district and the Roberts Mountains, Nevada, however, specimens are apparently not abundant. Walcott identified the two Devonian species found in the Eureka district as *Syringopora perelegans* Billings and *S. hisingeri* Billings. Both species are readily distinguishable from the common Mississippian forms. An examination of the Syringoporas in the Survey's Devonian stratigraphic collections indicates that the form called *S. perelegans* is the species commonly associated with diagnostic Devonian faunal assemblages in this region.

" 'The small horn corals, though not identifiable as to genus, appear to be the zaphrentoid types that are so common in the lower Mississippian in this country.

" 'A considerably more diversified coral faunule, including caninoids and clisiophyllids as well as zaphrentoids and syringoporoids, was obtained at a later date from the upper part of the Tin Mountain limestone at the type locality (collection U-606). Studies of these corals are not yet completed, but I do not think there can be any doubt that the assemblage is of Carboniferous age.'

"The brachiopods, though not specifically determinable, also suggest Mississippian age. They have been designated as *Spirifer* cf. *S. centronatus* Winchell and *Composita?* sp. indet.

"Collection U-200 consists mostly of brachiopods, but contains two fragmentary and silicified horn corals. Miss Duncan examined the horn corals, and the brachiopods were examined by Edwin Kirk, G. A. Cooper, Arthur Bowsher, and me. All agree that the brachiopods represent a fauna that is very probably of very early Mississippian age, but definitely diagnostic characters needed for positive identifications are preserved on so few of the individuals that a definite age reference cannot be made. A qualified determination as early Mississippian is the best that can be made on the material available to us. The following is a list of identifications, insofar as they may be made, prepared by me.

Horn corals, 2 specimens
Crinoid columnals
Echinoid plates
Shumardella? sp. indet.
Spirifer cf. S. centronatus Winchell
Spirifer? sp. indet.
Spirifer or Brachythyris sp. indet.
Composita? sp. indet.
Productella? sp. indet., part of an interior
Schizophoria? sp. indet.
Punctospirifer? sp. indet.

"Regarding the two horn corals listed above, Miss Duncan states:

" 'One specimen is a fragment from the calicular part of what is interpreted to be a zaphrentoid coral. There is too little of the corallum to tell what the genus might be. The larger specimen is incomplete and poorly preserved. It might be a Mississippian caninoid, but in some respects it seems to be more like a Devonian coral. Data from the corals in this collection are inconclusive.' "

As a working hypothesis it is proposed that the Tin Mountain limestone is equivalent to the lower part of the Madison group. This is based not solely on these properly noncommital identifications of fossils but also on the lithologic similarities in the sequence of rocks from the Devonian-Mississippian boundary well into the Mississippian, as described in areas between the Panamint Range and the localities of established Madison.

Correlation of the Tin Mountain limestone with the Mississippian rocks in the region around the Quartz Spring area is somewhat difficult because the Mississippian units there have not been named or defined. It occurs

widely in the adjacent Ubehebe Peak quadrangle and westward in the Inyo Range; conspicuously dark limestone in the Inyo Range is equivalent in stratigraphic position and lithology to at least the upper unit of the Tin Mountain limestone. Probably some part of the Mississippian (and older?) rocks described by Hopper (1947, pp. 409-411) in the northern end of the Argus Range, about 30 miles in a straight line south of the Quartz Spring area, is equivalent in age, if not as a lithologic unit.

In the Nopah Range, the lithologic description of only the highest unit (14C) of the Stewart Valley limestone (Hazzard, 1937, pp. 275 and 333) suggests equivalency to the Tin Mountain limestone; the two lower units appear to be more similar to the Devonian Lost Burro formation (see fig. 6). Hazzard's revision in 1951, however, extends the Monte Cristo limestone downward to include part of the original Stewart Valley limestone and drops the name "Stewart Valley limestone." The Mississippian formation in the Goodsprings area, the Monte Cristo limestone (Hewett, 1931, pp. 17-19), is lithologically unlike the Tin Mountain limestone although the faunas suggest at least approximate equivalency in age. The Bristol Pass limestone in the Pioche district is similar in lithology and age to the upper unit of the Tin Mountain limestone, and in the section south of Silverhorn (Westgate and Knopf, 1932, p. 17) the West Range limestone above the Devonian fossils near the bottom would then correspond to the lower unit of the Tin Mountain limestone. The remainder of the West Range limestone and underlying sandy part of the Silverhorn dolomite are not too dissimilar in rock type and age to be provisionally correlated with the top of the Lost Burro formation. In the Roberts Mountains region there seems to be no lithologic unit of Mississippian age equivalent to the Tin Mountain limestone. In the Ely area the dual combination of the nonresistant Pilot shale and the overlaying cliff-forming Joanna limestone (Spencer, 1917, p. 26) suggests the sequence of lower and upper Tin Mountain limestone; the little that has been published about their ages (Weller et al., 1948, p. 134) supports the suggestion.

Perdido Formation (Mississippian)

Name and Occurrence. The Perdido formation is here named for Perdido Canyon (pl. 1), where the formation is exposed from the foot of the southern wall, about 9,000 feet southeast of Quartz Spring, over the hill to the underlying Tin Mountain limestone. In the canyon, a fault between the Perdido and Rest Spring formations cuts out the uppermost part of the Perdido, but this segment is well exposed south of Rest Spring. The type locality extending south from Perdido Canyon, therefore, is supplemented by a second locality, about 3,000 feet south of Rest Spring, for the uppermost part of the Perdido formation.

The most conspicuous exposures lie in a much-faulted strip that trends north from the Rest Spring road, through the middle of the area to the northern border (figs. 9, 10, and 11). The southern part of the strip is readily accessible, but except along steep gullies the exposures are relatively poor, and unmapped minor faults, largely concealed by slope rubble, obscure the stratigraphic sequence. Excellent but less accessible outcrops occur in the northeastern part of the area.

FIGURE 9. Tin Mountain limestone, Ctm, above Lost Burro formation, Dlb, and below Perdido formation, Cp, on northeastern side of Bighorn Gap.

The upper part of the Perdido formation makes smooth rounded slopes covered with fine-sized rubble, or somewhat ribbed slopes (fig. 11). At favorable locations the lowest part of the formation makes cliffs, which are less pronounced than the cliffs made by the underlying Tin Mountain limestone.

Lithology. The Perdido formation lithologically is greatly diversified within one section and also from place to place, so that its heterogeneity is an outstanding characteristic. It is somewhat transitional from the underlying Tin Mountain limestone to the overlying Rest Spring shale, for in the lower part dark limestone is predominant over the interbedded chert, shale, and siltstone, and in the upper part shaly calcareous siltstone

FIGURE 10. Siltstone and silty limestone in Perdido formation, north of Bighorn Gap.

FIGURE 11. Rest Spring shale, Crs, faulted down against Perdido formation, Cp, south of Rest Spring.

or fine-grained sandstone is predominant over limestone. The limestone, both fresh and weathered, is medium gray and tends to break down into small platy fragments but less readily than the interstratified silty limestone. Most of the limestone is fine-grained, although some is coarsely clastic and is composed of crinoid columnals or a more varied assortment of shell fragments and pebbles. Some of the upper limestone contains considerable sand, which on weathering brown in the gray calcareous matrix may show cross-bedding. The chert ranges in color from grayish black to light gray and weathers from gray to brown. Much of the chert forms continuous beds, either sharply defined or appearing to grade into the adjacent dark limestone; some of it is a more or less incomplete replacement of crinoidal limestone, and a little forms elongate nodules. The clastic rocks, the most characteristic part of the Perdido formation, range from shale through siltstone and sandstone to conglomerate. Of these, siltstone is the most abundant. It is commonly light gray or pale red and weathers from yellowish to reddish browns. Near igneous intrusions it has been changed to vitreous quartzite, which also weathers brown. The coarse conglomerate occurs only locally, and consists of rocks from the Perdido formation. As exhibited south of Rest Spring, the 10-foot intraformational conglomerate layer may have been deformed while still unconsolidated. Its origin deserves further study.

The lithology of the Perdido formation at the type locality, as described below in the measured section, is representative rather than definitive of the formation, because at other localities, even nearby, the sequence varies greatly and the strata cannot be convincingly correlated. In general the siltstone is the most diagnostic feature of the Perdido formation. The lower part of the formation is distinguished from the Tin Mountain limestone by the siltstone, shale, or continuous beds of chert, in the preponderant limestone, although the two formations are somewhat gradational. Where poorly exposed the lower boundary may not be mapped (on pl. 1) at precisely the same stratigraphic position. The shaly character of the upper part may seem gradational with the Rest Spring shale, but the upper boundary is sharp and rarely questionable. The Rest Spring shale, unlike the Perdido formation, normally has no reddish tints and in this area consistently contains no limestone. On the geologic map (pl. 1), however, some exposures of the 5-foot uppermost unit (no. 11) of the Perdido formation are not distinguished from Rest Spring shale. This border unit, despite the lithology, at the time of mapping was considered to be the basal unit of the Rest Spring shale. The top of the Perdido formation in the Quartz Spring area, but not everywhere southwestward in the Ubehebe Peak quadrangle, invariably is marked by the grayish-red soft shale capped by a thin bed of fossiliferous limestone.

Section of the Perdido formation measured with a tape at the type locality starting south of Rest Spring:

Rest Spring shale.
(Conformable contact.)

Perdido formation:	Feet
11. Very soft shale, grayish red to grayish red purple, fossiliferous, at surface invariably breaks down to loose powdery material; capped by thin bed (about 6 inches to 1 foot) or lenses of dark-gray fine-grained limestone containing abundant excellently preserved *Cravenoceras*	5±
10. Thin to medium beds of medium-gray limestone, in places conspicuously sandy and cross-bedded; uppermost bed contains productids; interbedded thin layers of calcareous siltstone or sandstone	15±
9. Conglomerate of constituents as large as boulders (3 feet longest dimension), subangular to rounded, composed of limestone (some crinoidal, containing also horn corals and brachiopods), dark-gray chert, and grayish-red siltstone. The matrix is medium-gray limestone faintly tinged red, containing irregularly distributed silt, fine sand, and shell fragments, in places lenticular and channel-bedded. Local and essentially intraformational	10
8. Calcareous siltstone, somewhat platy, pale red weathering reddish brown, but in places moderate yellowish brown to grayish orange weathering light to moderate brown	85

Section continued at the type locality south of Perdido Canyon:

7. Interbedded chert, siltstone, and limestone; chert ranging from grayish black to light gray, acquiring brownish tinges on weathering, some clearly a replacement of crinoidal limestone; siltstone as in unit 8; limestone medium to light gray, subordinate to chert and siltstone; base marked by 2-foot light-gray clastic crinoidal limestone under 11-foot layer of grayish-black chert	70
6. Poor exposure of platy limestone, dark chert; at base, 5 to 10 feet of clastic limestone (limestone pebbles, shell fragments) containing chert lenses	85
5. Limestone and chert float	41
4. Light-gray shale, somewhat siliceous	20
3. Impure limestone, silty and cherty, containing some fine-grained conglomerate; fossiliferous	32
2. Thin-bedded limestone and chert making massive unit	22
1. Interbedded limestone, siltstone, silty limestone, and chert; limestone medium gray, weathering into platy chips from layers 2 to 3 feet thick, which make ribs on moderate slopes; siltstone and silty limestone range from reddish brown to light gray, weathering yellowish browns; chert makes thin continuous beds in ribby limestone; about 20 feet from top, conspicuous 6-foot bed predominantly chert, brown weathering	225
	610±

(Conformable contact.)
Tin Mountain limestone.

A section of the Perdido formation, about 7 miles in a straight line west of the section at Perdido Canyon, was measured at the mouth of the prominent constriction in the canyon below Ubehebe mine (about 1 mile straight N. 70° W. of the mine). A brief description of it follows:

Rest Spring shale.
(Possibly fault contact.)

Perdido formation:	Feet
(Numbers of units do not correspond to numbers in previous section.)	
5. Olive-gray and olive-brown silty limestone, breaking into small angular fragments in slope rubble, which, starting 13 feet above base of unit, covers it for 46 feet; somewhat hornfelsic in places; upper part medium gray, weathering olive gray	115
4. Dark argillaceous limestone; abundant grayish-black chert in upper 8 feet; more argillaceous, weathering reddish brown in lower 12 feet; poorly exposed	20
3. Medium dark gray crinoidal limetone, weathering as massive unit	25
2. Medium dark gray conglomeratic limestone; scattered pebbles, cobbles, and boulders of dark-gray chert and of limestone distinct from matrix, up to 2 feet long and 1 foot thick, well rounded	10
1. Medium dark gray limestone, cherty in places; upper half preponderantly shale or siltstone, weathering into small platy fragments; also somewhat argillaceous near base, weathering into platy fragments	50
(Conformable contact.)	220

Tin Mountain limestone.

Thickness. According to the composite section measured with a tape at the type locality, the thickness of the Perdido formation is 610 feet. There is some doubt concerning the accuracy of matching the top of the part measured south of Perdido Canyon with the bottom of the part measured south of Rest Spring. The error, if actual, is in omitting about 75 feet of siltstone above unit 7. Despite uncertainties caused by the combination of lithologic changes and faults, it is believed that from place to place the thickness of the formation varies within a wide range, and that the greatest thickness in a large region between Death Valley and the Inyo Range occurs between Perdido Canyon and Rest Spring. In the canyon below Ubehebe mine, west of the Quartz Spring area, the Perdido formation is only 220 feet thick. The somewhat abrupt variation in thickness suggests a disconformity, and the intraformational conglomerate within the Perdido formation suggests that the disconformity is within the formation.

Age and Correlation. The fauna in the uppermost 5 feet of the Perdido formation has a close affinity to the White Pine shale fauna of eastern Nevada (Miller and Furnish, 1940; Youngquist, 1949) and of the Inyo Range (Kirk, 1918, pp. 38-39) and is similar to the Caney fauna in Oklahoma as described by Girty (1909). Some of the best-preserved fossils of the Quartz Spring area were collected from this zone, and in 1939 they were deposited in the paleontologieal collection of Stanford University. The fauna's most noteworthy form, which is unusually well preserved in a thin limestone and is abundant throughout the area, is a diagnostic goniatite, which in 1937 compared well with *Gastrioceras richardsonianum* Girty (1909, pp. 54-57, pl. XI) of the Caney and White Pine assemblages (Kirk, 1918, p. 39). The form has since undergone reclassifying (Plummer and Scott, 1937; Youngquist, 1949, etc.). It is closely related to the *Cravenoceras* in the lower part of the Upper Carboniferous in England (Bisat, 1924), which corresponds to the top of the Mississippian in the United States (Weller et al., 1948, chart no. 5, pp. 107-1-9). Thus the top beds of the Perdido formation are of Chester age, that is, of late Mississippian. In 1950 J. H. Peck, Jr., from the University of California, collected fossils from this zone in the Quartz Spring area (oral communication, 1950) and on reporting the occurrence of *Rayonnoceras* in the zone, states that the fauna appears to be a correlative of the White Pine shale of Nevada and the Caney shale of Oklahoma (Peek, 1951).

Meager collections of poorly preserved fossils from lower zones in the Perdido formation were collected in 1948 during work on the stratigraphy of the Ubehebe Peak quadrangle. The only collection (U-438) within the Quartz Spring area is from a locality 1 mile S. 15° W. of Rest Spring (see pl. 1). The exact stratigraphic position is not known, but it is below the calcareous siltstone of unit 8 at the type locality, and probably in unit 7. Excerpts from the report by James Steele Williams (written communication, 1949) are quoted:

> "U-438 is the lowest of the Perdido collections [at that time]. It is also the most varied, but unfortunately none of the forms can be definitely identified. The corals and the bryozoans, as reported by Miss Duncan, consist of 'small zaphrentoid(?) corals, fragmentary and silicified so as to prevent identification, a very large horn coral that is unidentifiable because the axial part of the apical and ephebic regions is missing, and a few fragments of silicified bryozoans, probably stenoporoids and rhomboporoids.' In addition to the corals and bryozoans, there are crinoid columnals, several fragmentary or incomplete brachiopods, identified as *Dictyoclostus?*, possibly 2 sp. indet., *Rhynchopora?* sp. indet., *Composita?* sp. indet.; several gastropods preserved as internal molds that are indeterminable; and several coiled cephalopods. The gastropods include a high-spired form, several bellerophontid types, and a euomphalid type. It is impossible to identify gastropods such as these without the ornamentation being preserved, as the genera and species are based in part on features of the ornamentation. The nautiloids are also not determinable. . . . One of the brachiopods identified as *Dictyoclostus?* sp. indet. resembles in some ways *D. inflatus* (McChesney), a common late Mississippian and early Pennsylvanian species, but no definite identification can be made.
>
> "Collection U-438 is definitely post-Devonian and, of course, pre-Mesozoic. Though a definite reference closer than that cannot be made, the faunal aspect suggests a late Mississippian fauna . . ."

All but one of the other Perdido collections submitted from the Ubehebe Peak quadrangle contained even poorer specimens and were less diagnostic of age. The exception (U-541), although it is from a locality 22 miles southwest of Quartz Spring, deserves attention because it marks the lower limit of the Perdido formation. The fossils were collected from the basal bed of the Perdido formation lying on Tin Mountain limestone 2¼ miles N. 62° E. of Cerro Gordo bench mark. The report by James Steele Williams follows:

> "U-541 is from the Perdido formation. It consists of horn corals and a few crinoid columnals. The crinoid columnals are of no age significance. Miss Duncan lists the corals as follows:
>
> Hapsiphyllum? sp. indet.
> Homalophyllites? sp. indet.
> Cyathaxonia? sp. indet.
> Caninia cf. C. cornicula (Miller)
> Other small zaphrentoid corals
>
> "Her remarks concerning the collection are as follows: 'This collection is somewhat more adequate than several of the others so far as the number of specimens is concerned; however, some of the specimens are fragmentary and all are somewhat silicified. Identification is therefore doubtful. The assemblage looks very much like what might be expected in the Kinderhook (Chouteau) or Osage faunas of the Mississippi Valley region.'"

In summary, the age of the Perdido formation is Mississippian, which is shown by its stratigraphic position above the Tin Mountain formation and below the

White Pine fauna. Based on doubtful identifications of inadequate collections of fossils, the formation includes rocks ranging in age possibly from Osage or late Kinderhook into Chester. The completeness of the local sedimentary record during that long interval will not be known until better fossils are collected, and the best answer lies in the Quartz Spring area rather than in the region for many miles around.

The difficulty of correlating the Perdido formation, as a cartographic unit, with other Mississippian formations is understandable on considering the diversity displayed by the formation in a small area. The White Pine shale of the Inyo Range, as described by Kirk (1918, p. 38) and as observed by the writer, is in part lithologically equivalent to the Perdido formation, but the White Pine includes also equivalents of the Rest Spring shale. The Mississippian rocks in the Argus Range have not been named as formations and have been insufficiently described for an adequate comparison. The Monte Cristo limestone in the Goodsprings district and in the Nopah Range, although in an equivalent stratigraphic position, does not closely correspond in lithology to the Perdido formation. In central and eastern Nevada, the stratigraphic columns of the Roberts Mountains region and of the Ely district have no described lithologic equivalents of it. In the Pioche district, however, the Peers Spring formation and at least part of the Scotty Wash quartzite, as described by Westgate (1932, pp. 20-22), are convincingly similar to the Perdido formation.

Rest Spring Shale (Pennsylvanian(?))

Name and Occurrence. The Rest Spring shale is here named from the extensive exposure around Rest Spring. The type locality extends from the head of the gulch 2,000 feet south of Rest Spring (see fig. 11) northward to within 200 feet of the top of the hill that is 2,000 feet northwest of Burro Spring. The Perdido formation lies conformably below and the Tihvipah limestone above the Rest Spring shale.

The Rest Spring shale covers a large proportion of the Quartz Spring area, especially in the northeastern quadrant where it makes a continuous belt 4 miles long and 1 mile wide (see pl. 1). Isolated patches are exposed along the major fault zone from Hidden Valley to the Gap Hills on the northern boundary. This widespread occurrence, fortuitous in the small area that was mapped, is far from representative of the whole region in which the formation is found.

It is by far the most easily eroded formation in the Paleozoic sequence of the region; hence in places of active erosion it normally controls drainage lines. The seemingly anomalous occurrence of the Rest Spring shale in the highest part of the Quartz Spring area is explained by the protecting margin of resistant intrusive rock and of cherty limestone in the Perdido and Tin Mountain formations at a place recently exposed. The slopes that develop on the formation are smooth and rolling (fig. 11).

Lithology. The characteristic rock of the Rest Spring shale is argillaceous shale grading into siltstone. It is olive gray on the surface, but some of the fresh shale, as exposed in the excavation to develop Rest Spring, is dark gray. The basal shale contains discoidal concretions 2 to 6 inches in diameter, which are sufficiently persistent to be excellent markers of the lowest part of the formation. The nuclei of the concretions consist of calcite and pyrite or limonite; some are septaria. The shale grades upward into siltstone, fine-grained sandstone, and in some places thin isolated beds of light-gray quartzite. Some of the standstone is conglomeratic, in thin, very inconspicuous beds. The conglomerate is further described below in the generalized stratigraphic section of the formation. The sandy and conglomeratic layers show the effects of channeling and cross-bedding, and in some exposures the siltstone displays ripple marks.

A thin section of silty and sandy shale contains in a matrix of very fine-grained material many angular fragments of quartz, commonly 0.08 millimeter in diameter, and fragments of fossils, which mostly are of calcite but a few were replaced by fine-grained quartz. The specimen is somewhat phosphatic.

The incompetence of the Rest Spring shale has favored igneous intrusions and thrust faults. Thin sills of highly sericitized feldspathic rock, which at first glance may be taken for sedimentary layers, are locally common in the formation. Within the aureoles of larger intrusions the Rest Spring shale has been metamorphosed to chiastolite-bearing hornfels and, nearest the igneous contacts, to biotitic hornfels and schist. In thrust zones much of the shale is moderate red or reddish brown, a sharp contrast to the normal olive gray.

No complete stratigraphic section of the Rest Spring shale has been measured in the Quartz Spring area. Complex structures, generally covered by finely broken shale in slope rubble, could not be mapped and precluded measurement of the true stratigraphic sequence. A composite description of the two graditional units, largely without data on thickness, follows:

Tihvipah limestone.
(Conformable contact.)
Rest Spring shale:

2. Olive-gray siltstone and shale, sparsely fossiliferous; locally thin beds of light-gray or olive-gray quartzite, in places metamorphosed by sills to vitreous quartzite; thin local intraformational conglomerate of poorly sorted fragments rarely as much as 1 inch or 2 inches in diameter, mostly subangular, some fairly well rounded but others angular, composed of olive-gray siltstone or shale, white or gray quartzite, and gray dolomite, in a matrix of coarse sand or rarely in a matrix of fragmented shells. Some measured details at one locality follow:

	Feet
Light olive gray quartzite, grading into siltstone in upper 10 feet	15
Porphyry sill	20
Light-gray quartzite, weathering reddish or yellowish brown; thin-bedded but breaking into blocks	4
Olive-brown siltstone, breaking into angular fragments 1 inch or less in diameter	20
Quartzite similar to the stratigraphically higher light-gray quartzite	6
Olive-gray siltstone	63
Sill	5
Olive-gray shale of underlying unit, not measured.	

1. Olive-gray argillaceous shale, grayish black where completely fresh; very readily disintegrates into small incipiently lustrous chips; near base typically contains discoidal concretions around mineral nuclei including septaria; concretions commonly between 2 and 6 inches in diameter and as much as 2 inches thick.

(Conformable contact.)
Perdido formation.

Thickness. In the Quartz Spring area the stratigraphic thickness of the Rest Spring shale could not be measured because of the complex structure and poor exposures. West of the area, 1.1 miles N. 75° W. of Ubehebe mine

(fig. 1), the formation is somewhat more than 400 feet thick. At a better exposure 3 miles N. 70° E. of the southwestern corner of the Ubehebe Peak quadrangle (fig. 1) the Rest Spring shale is 310 feet thick. The extreme incompetence of the Rest Spring shale relative to the adjacent rock units permits the formation to pinch and swell in zones of folds and faults, so that little confidence can be placed in these measurements of thickness.

Age and correlation. Fossils are very scarce in the Rest Spring shale. The few that were collected early in the field work and were deposited at Stanford University have not been identified. They include impressions of elongate reedlike leaves, which are the only fossil plants from the area. Along with bryozoan fragments in a thin section (collection of S. W. Muller, Stanford University) there are some poorly preserved microfossils, some of which are eccentric coils and others are spindle-shaped coils about 1 millimeter long, suggesting minute Foraminifera. In the Ubehebe Peak quadrangle, fossils have been found in the formation at only one locality, at the southwestern margin of the quadrangle. These fossils (U-324) were collected for the U. S. Geological Survey by Raymond Douglass, from somewhat metamorphosed shale. Comments by James Steele Williams (written communication, 1949) about this collection, from a locality about 2.8 miles N. 60° E. of the southwestern corner of the Ubehebe Peak quadrangle follow:

> "Only one collection, U-324, has come from this formation. It is shown as obtained from near but not at the base of the formation. The matrix is a hard, compact black shale or argillite and is so baked that none of the fossils is definitely determinable. Impressions or fragmentary remains suggest brachiopods belonging possibly to the genera *Chonetes*, *Marginifera*, and *Composita*, but even the generic identifications are uncertain. The fragmentary remains have slightly, but very slightly, more resemblance to Pennsylvanian species of these genera than to Mississippian species, but the age might as well be Mississippian as Pennsylvanian."

The uncertain identification of these poorly preserved fossils cannot be used to determine the age of the Rest Spring shale. The stratigraphic relationships are unequivocal: the formation lies above the late Mississippian fauna in the uppermost part of the Perdido formation and below the moderately early Pennsylvanian fauna in the lowest part of the Tihvipah limestone. Provisionally, the Mississippian-Pennsylvanian boundary is drawn arbitrarily at the base of the Rest Spring shale.

The Rest Spring shale lithologically corresponds to the black, fissile, noncalcareous, shaly part of the White Pine shale in the Inyo Range (Kirk, 1918, p. 38). There the White Pine shale includes, however, equivalents of the Perdido formation. The Caney-White Pine fauna was reported to occur in black shale north of the Cerro Gordo mine in the Inyo Range, but it is not known if this fauna is at the base of the black shale, as it is in the Quartz Spring area, or well within the black unit. This fauna in the Quartz Spring area, containing *Cravenoceras*, was included in the Perdido formation because the thin limestone and reddish shale that have the fossils are lithologically consistent with the rocks in the Perdido formation and not with the dark shale and siltstone of the Rest Spring.

The description of the Chainman shale at Ely (Spencer, 1917, p. 27) fits the Rest Spring shale. There may be some difference in age of the two units, as fossils from the upper third of the Chainman shale, though containing a suggestion of Pennsylvanian affinity, were assigned tentatively to the upper Mississippian. At Devils Gate, south of Roberts Mountains in east-central Nevada, the dark shales and sandy interbeds that Merriam (Merriam and Anderson, 1942, pp. 1690-1691) describes in the Diamond Peak beds resemble the Rest Spring shale. Merriam includes these black shales in the Diamond Peak, although in the Eureka district they had been referred by Hague to the White Pine shale. The black fissile part of the White Pine shale of Nevada, as described by Youngquist (1949, pp. 276-283) in connection with his detailed description of the cephalopod fauna, appears to be lithologically equivalent to the Rest Spring shale. But if in Nevada the *Cravenoceras*-bearing limestone is confined to the top of the shale, the lithologies and ages of the two units are not strictly equivalent; there is no question about the position of the only *Cravenoceras*-bearing limestone being contiguously below the black shale in the Quartz Spring area.

Tihvipah Limestone (Pennsylvanian)

Name and Occurrence. The limestone and associated rocks above the Rest Spring shale are here named the Tihvipah limestone from the exposure northwest of Tihvipah Spring, which is 2 miles N. 15° E. of Burro Spring. The name Tihvipah Spring does not appear on any previously published map, but in 1938 it was used by the rangers of the National Park Service in Death Valley. The type locality of the Tihvipah limestone is on the hill due east of Rest Spring, which is far more accessible than the exposure near Tihvipah Spring. In the Quartz Spring area the top of the Tihvipah limestone is eroded so that its upper limit cannot be satisfactorily defined. Between Racetrack Valley and Saline Valley it is the lowest unit of a thick sequence of limestones and shales of Pennsylvanian-Permian age. The Tihvipah limestone caps hills in the central belt of Rest Spring outcrops and in the Gap Hills, making smooth rounded slopes except where moderately ribbed by more resistant limestone beds.

Lithology. The Tihvipah limestone consists mostly of platy light-gray limestone, interbedded with shaly limestone or calcareous shale and some beds, 1 foot to 3 feet thick, of fine-grained medium-gray limestone. The shaly rocks range in color from very light gray to pale red or grayish pink. Dark fusulinids and fragments of other fossils in a light-gray matrix form abrupt lenses, in section, as if in filled channels. The most diagnostic widespread characteristic is spherically concretionary dark-gray chert in balls ranging from about $\frac{1}{10}$ inch to 2 inches in diameter. Many of the chert spheroids are about $1\frac{1}{2}$ inches in diameter. In some places the nodules are somewhat flattened or coalesce, thus becoming less diagnostic of the formation. These concretions are readily distinguished from the rounded chert pebbles, 1 inch or less in diameter, which compose a local, inconspicuous, thin basal conglomerate.

Thickness. No section of the Tihvipah limestone has been measured in the Quartz Spring area, where the exposures are incomplete or complicated by local structures. West of the area, 1.2 miles N. 76° W. of the Ubehebe mine (fig. 1), the Tihvipah unit of the still unnamed Pennsylvanian rocks is about 200 feet thick.

Age and correlation. The few fossils collected early in the field work, and now in the collection at Stanford University, have not been identified. Lloyd G. Henbest of the U. S. Geological Survey contributed the following

information about his collection from the type locality, approximately 1,000 feet due east of Rest Spring, and from within 100 feet stratigraphically above the base of the Tihvipah limestone (Henbest, written communication, 1952).

F-7078 Tetularriidae
Bradyina? sp.
?Fusulinella, 2 sp.

"The generic identity of the one and probably two species referred to *Fusulinella* is difficult to ascertain. The preservation is not good and the question might be difficult if the preservation were good. The problem here reduces to a question whether one of the species belongs to *Fusulinella* and the other to *Fusulinella* or a primitive form of *Fusulina* or whether both belong to very early forms of *Triticites* such as, for example, *Triticites pygmaeus* Dunbar and Condra. The evidence is ambiguous, but it seems to favor the alternative that these represent lower-middle Pennsylvanian forms of *Fusulinella* and *Fusulina?* I can not demonstrate that these are not early Missourian forms of *Triticites*. In fact some specimens appear to have the shell structures that characterize *Triticites*.

In summary, the age seems definitely to be Pennsylvanian and to favor late Atoka or early Des Moines age. Early Missouri age must be regarded as a possibility. Permian age seems to be definitely improbable.

The Tihvipah limestone retains its lithologic identity in the southwestern corner of the Ubehebe Peak quadrangle and as far away as the western side of Mazourka Canyon along the foothills of the Inyo Range near Independence. The Tihvipah limestone probably is equivalent to a small part of the Bird Spring formation of Pennsylvanian age in the Goodsprings district, Nev. (Hewett, 1931, pp. 21-30) and to the basal part of a thick sequence of Pennsylvanian and Permian rocks in the Ubehebe Peak quadrangle and adjacent region.

Older Gravel (Pleistocene(?))

Remnants of continental deposits that are older than the Recent alluvium are exposed at the northern end of Hidden Valley, in the basin draining through Leaning Rock Canyon, on the southeastern flank of east crest, and along the western foot of the Gap Hills. On the geologic map (pl. 1) the older gravel has not been distinguished from Recent deposits. A considerable part of the older gravel consists of poorly sorted continental sediments similar to the Recent alluvium but it is somewhat more consolidated and in general slightly stained with limonite. In many places the dips are steeper than the greatest initial dips in the present-day alluvial fans.

The most distinctive characteristic of the older deposits is the volcanic material. White beds of pumice, commonly 2 to 4 feet thick, consist of fragments as much as 3 inches in diameter, although most are a fraction of an inch. Some of the pumiceous material is remarkably free of other rock constituents. Other beds in the gravel contain fragments of weathered basaltic material, which is much less conspicuous than the pumiceous material. Within the mapped area there is no evidence of the age of the gravel other than that it is younger than Pennsylvanian and older than Recent. The amount of deformation and erosion suggests that the age is Pleistocene. Other pumiceous gravels in the Death Valley-Owens Valley region have been called Pliocene or Pleistocene (Kirk, 1918, pp. 48-57; Hopper, 1947, pp. 415-416). No attempt, however, is made here to correlate any of these older gravels with the older gravel in the Quartz Spring area.

STRUCTURE

Structurally the Quartz Spring area consists of a western block thrust over the margin of an eastern block of undulating and openly folded beds. North-trending normal faults cut both blocks, and small masses of syenitic rock intrude part of the eastern block. In detail the structure is complex, and many of the structural elements are relatively short. Some of the details are not shown on the geologic sketch map (pl. 1) nor in the structure sections (pl. 3), which thus acquire a somewhat diagrammatic aspect, particularly where Rest Spring shale covers the surface.

The deformation occurred sometime after early Pennsylvanian time, but how long after is not shown by the sedimentary record in the area as there is a large gap between the early Pennsylvanian Tihvipah limestone, which was involved in the deformation, and the Pleistocene(?) gravel, which was merely tilted at some places. In the southern Death Valley region the major orogeny, including low-angle thrust faulting, is regarded by Noble (1941, p. 959) as middle or late Tertiary in age. Twice as far to the southeast, in the Muddy Mountains of southern Nevada, some major thrusting according to Longwell (1949, p. 965) "may represent orogeny either late in the Jurassic or during the Cretaceous before Bear River time" and other thrusting "may have occurred either in the late Cretaceous or in Tertiary time." Rather than suggest correlation with orogenies in southern Death Valley or southern Nevada, it seems more reasonable to correlate the folding, thrusting, and igneous intrusion in the Quartz Spring area with similar Nevadan deformation in the nearby Inyo Range and Sierra Nevada, and to correlate the normal faulting with the Tertiary and later normal faulting that is well dated in other parts of the Great Basin. The geology of the small Quartz Spring area adds no precision to the timing of deformation in the Basin Ranges (see Longwell, 1950, pp. 422-427).

Thrust Faults

Thrusting of the western block toward the east made an exceedingly complex zone 1 mile to 2 miles wide, which contains several thrust faults, imbricate structure, and some intricately deformed rocks. The western side of the thrust zone is largely covered by alluvium in Racetrack Valley, except near Quartz Spring; the eastern margin extends from the range front at the Gap Hills, through Bighorn Gap and Perdido Canyon to the alluvium in Hidden Valley (see pl. 1).

The Racetrack thrust fault (see fig. 12), at the western border of the exposed thrust zone, is the major fault in the mapped area, as it has the greatest stratigraphic throw and can be traced the greatest distance beyond the area, that is, about 10 miles southward along the eastern side of Racetrack Valley. West of Quartz Spring the maximum stratigraphic throw is about 5,700 feet, where Ordovician Pogonip limestone lies on Carboniferous Rest Spring shale; and 8 miles south, in a low saddle southeast of The Racetrack playa in the Ubehebe Peak quadrangle, the stratigraphic throw is at least 8,500 feet, placing Cambrian Racetrack dolomite over Carboniferous Perdido formation. Rest Spring shale outlines much of the Racetrack thrust near Quartz Spring, where steeply overturned Pogonip limestone, along with a few slivers of Eureka quartzite and Ely Springs dolomite, lies on a

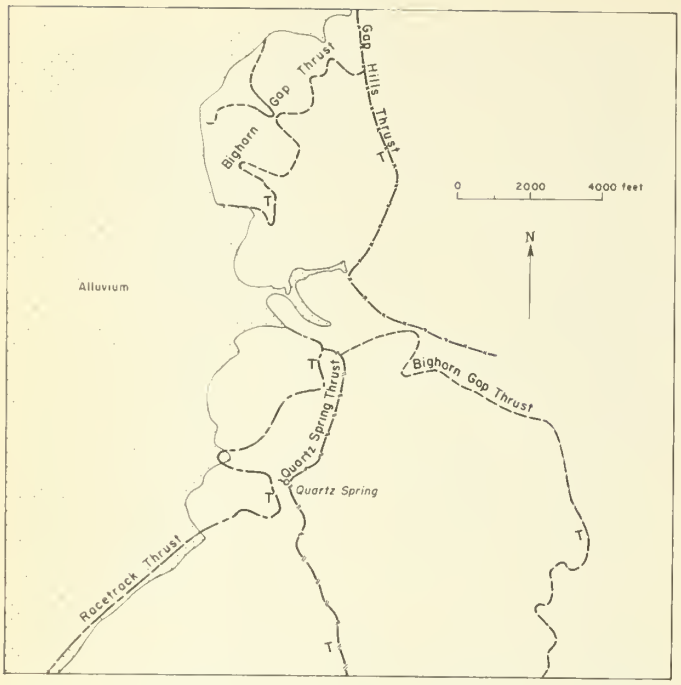

FIGURE 12. Outline map of principal thrust faults near Quartz Spring. T marks upper plate. The Racetrack thrust is projected under alluvium.

chaos of upper Paleozoic formations. The thrust surface dips about 25° W. The more even part of the range front southwest of Quartz Spring also slopes about 25° and the beds in it are turned up, suggesting that it is substantially the stripped surface of the Racetrack thrust fault (see fig. 2).

The eastern margin of the complex zone, at the northern end, is outlined by the lowest exposed thrust, referred to as the Gap Hills thrust fault (see fig. 12 and pl. 3, sec. A-A′). The remainder of the eastern margin is outlined by normal faults that dropped the thrust complex down on the west. The trace of the Gap Hills thrust fault lies between the Gap Hills and the range front and curves southeastward into Bighorn Gap. The range front east of the hills is essentially the thrust fault stripped by erosion. The greater steepness at the range front, although possibly an initial curvature in the fault surface, probably is a post-thrust warp that broke into normal faults through Bighorn Gap and Perdido Canyon. Beneath the Gap Hills thrust southeast of the hills the Lost Burro, Tin Mountain, and Perdido formations locally were dragged up and steeply overturned. The Rest Spring shale and Tihvipah limestone in the overriding block were greatly crushed and faulted but left upright. The maximum stratigraphic throw, Rest Spring shale on Lost Burro formation, probably amounts to somewhat less than 1,500 feet.

Within the zone between the Gap Hills thrust and the Racetrack thrust the most conspicuous fault is called the Bighorn Gap thrust. It extends from where it joins the Gap Hills thrust on the northern side of the Gap Hills, under alluvium south of the hills, then eastward through Bighorn Gap, and southward to Perdido Canyon, where it is faulted down (see pl. 1). The block overlying the Bighorn Gap thrust is steeply overturned. Reverse and thrust faults east of Quartz Spring piled up segments of the block (see fig. 12, sec. B-B′). The overturned sequence extends from Pogonip limestone stratigraphically upward to the Perdido formation. Sufficient lithologic characteristics and fossils remain to distinguish each formation in the correct order, but at many places the characteristics are too obscure to outline the boundaries of the formations or to account for many anomalies. Erosion has exposed in Bighorn Gap and in the Gap Hills parts of the Bighorn Gap thrust where Lost Burro formation, overturned on Tin Mountain limestone, moved on Rest Spring shale. Some blocks of the Perdido formation south of the Gap Hills, where all are not distinguished from Rest Spring shale on the map (pl. 1), also were overridden by the Bighorn Gap thrust.

Between the Bighorn Gap thrust block and the Racetrack thrust near Quartz Spring there is still greater structural complexity, details of which are not shown on the map (pl. 1). Locally in this zone shattered blocks of the sequence from the Lost Burro formation to Rest Spring shale were overturned or inverted and pushed along the Quartz Spring thrust fault (see fig. 12) over Pogonip limestone. Rest Spring shale was dragged along some of the faults.

On the highland east of the complex thrust zone, various blocks of Tihvipah limestone were shoved over or into the Rest Spring shale. This is clear where the blocks are on brecciated Tihvipah formation, as exhibited east of Rest Spring, and where the topography exposes the structural breaks, as it does southeast of Burro Spring. The displacement of other blocks is inferred by the thinning or absence of Rest Spring shale between them and the underlying Perdido formation. No attempt has been made to show inferred structures through the incompetent and rubble-covered Rest Spring shale. These complexities may indicate that an overriding mass on the Gap Hills thrust fault was not far above the present topography.

Near the eastern margin of the mapped area (pl. 1) a steep fault of considerable displacement extends from a syenitic stock southward along the western base of Whitetop Mountain and across Leaning Rock Canyon to the eastern flank of the range. The fault will be referred to as the Leaning Rock fault. Although the dip of the fault has not been determined, the curvature of the adjacent rocks suggests it is a reverse fault dipping east, which is the interpretation followed in the structure sections (C-C′, F-F′, pl. 3). Merely on the basis of stratigraphic displacement, however, it could be a normal fault dipping west or a nearly vertical strike-slip fault along which the eastern block moved south. Strata on Whitetop Mountain curve conspicuously down toward the upturned ends of the strata on the other side of the fault (pl. 3, sec. F-F′). Ely Springs dolomite was placed against Perdido formation, making the stratigraphic throw as much as 4,000 feet where well exposed; but under the alluvium to the south, where Pogonip limestone abuts on Rest Spring shale, the stratigraphic throw is probably more than 5,000 feet. On the eastern flank of the range, in the southeastern corner of the mapped area, the Leaning Rock fault was displaced down on the east by a normal fault and was covered by gravel, a remnant of which still conceals it. The concealed part of the Leaning Rock fault accounts for the seeming anomaly of Pogonip limestone dropped down against Lost Burro formation, which is stratigraphically higher. (See pl. 3, sec. C-C′.)

Folds

The folds are mostly drag along faults. A drag upward under the Gap Hills thrust fault, well exposed between Bighorn Gap and the Gap Hills, involved Lost Burro, Tin Mountain, and Perdido formations in an overturned syncline. Similar overturning of Perdido formation, exposed in a high basin between Quartz Spring and Lost Burro Gap, was produced by the drag of an overriding block. Southwest of Whitetop Mountain Eureka quartzite and Ely Springs dolomite clearly show the bending down to the Leaning Rock fault, and on the other side of the fault Tin Mountain and Perdido formations as clearly show the upward fold (see pl. 3, sec. F-F′).

A fold not made along a fault is in the northeastern part of the mapped area, 1½ miles northeast of Burro Spring. It is a short anticline or dome elongated southward (see pl. 3, secs. A-A′, B-B′, and D-D′). A syncline on the eastern flank is obscured by intrusive masses and a thrust fault.

Normal Faults

The normal faults of the Quartz Spring area can be grouped into three north-trending zones located as follows: in the Last Chance foothills, in the central part of the area from Bighorn Gap to the Andy Hills, and along the eastern crest of the range. The only discernible effect on the existing topography has been to influence differential erosion.

A long north-trending normal fault in the Last Chance foothills shows the greatest displacement. As expressed by the trace on eroded topography, the fault dips about 50° E. The effect on the Racetrack-Nopah contact was to displace it 3,000 feet horizontally and to produce a stratigraphic throw on the order of 1,000 feet. Two faults of small displacement are shown (pl. 1) branching northeastward, making a wedge in the downthrown block of the main fault. Other normal faults in the foothills west of the mapped area also trend north.

In the central belt of normal faults, a set of faults through Bighorn Gap shifted the western side down. The displacement along this set diminishes northward to extinction at the range front, and southward it diminishes greatly to where it is lost in surface rubble of the Perdido formation and beneath the alluvium from Rest Spring Gulch. The same shift, however, is taken up by the essentially vertical fault through Perdido Canyon. These faults may be a subsidiary expression of the structural downwarp along the western front of the range. Thus the block that was warped down northeast of Gap Hills yielded by breaking around the re-entrant outlined by the Bighorn Gap and the Perdido Canyon faults. Other normal faults in the central zone are downthrown on the east and are of minor displacement.

The normal fault east of Whitetop Mountain and Leaning Rock Canyon, though poorly shown at the margin of the map (pl. 1), exhibits conspicuous downthrow to the east. The dip slip is possibly 1,000 feet, leaving uppermost Ely Springs dolomite opposite the base of the Eureka quartzite. The normal displacement is obscured in the southern part, where the old gravel that covers the Leaning Rock fault is faulted down against the Lost Burro formation (see pls. 1 and 3, secs. C-C′ and F-F′).

A fault along the western side of the same crest locally makes the crest-block a horst. Along the westward-dipping fault Tin Mountain limestone was dropped against Lost Burro formation. The northern end of the fault is concealed by an old gravel.

IGNEOUS ROCKS

Intrusive alkalic rocks, largely leucosyenite, occur in the northeastern quadrant of the Quartz Spring area (pl. 1) and also crop out sporadically down the eastern slope of the Panamint Range to the foothills in Death Valley (McAllister, 1940). They form dikes, sills, and chonoliths. The largest masses in the mapped area are between 2,000 and 3,000 feet wide, and the longest is about 2 miles. The contacts are generally concordant with the Rest Spring shale and Perdido formation, but are intricately discordant across the Tin Mountain limestone, Lost Burro formation and the undifferentiated metamorphosed lower Paleozoic limestone and dolomite. In other parts of the area, well-sericitized sills and dikes occur in the Rest Spring shale. Soda syenite about 11½ miles southeast of Tin Mountain, as described concisely by Ball (1907, pp. 207-208), appears to be the same kind as much of the syenitic rock in the Quartz Spring area. At both places the rocks are "characterized by abrupt and great changes in granularity and in the relative abundance of the constituent minerals" (Ball, 1907, p. 208).

Age and Correlation

The igneous rocks, considered as diaschistic offshoots from quartz-monzonite, are correlated with the quartz-monzonite of the Inyo Range and are regarded as Cretaceous(?) in age. In the Quartz Spring area, however, the stratigraphy dates the emplacement no more closely than post-Carboniferous. Southwest of the area exposures clearly show that small masses of leucosyenite occur as border facies and offshoots of quartz-monzonite (Ball, 1907, pp. 206, 208; McAllister, Geology of the Ubehebe Peak quadrangle, in preparation). Quartz-monzonite [5] is widely exposed in the northern part of the Panamint Range south of the area and almost continuously to the Inyo Range, where according to Knopf's reconnaissance map (1918, pl. 2) it is Early Cretaceous.

There is some difference of opinion about the age of the plutonic rocks in the Inyo Range and surrounding region. Ball (1907, pp. 207-209, pl. 1) calls those in the northern Panamint Range post-Jurassic and pre-Tertiary. Knopf mapped those in the Inyo Range as Early Cretaceous, but makes broad reservations in the text (Knopf, 1918, pp. 60, 62, pl. 2). The same intrusive complex in the Coso Range is called late Jurassic by Hopper (1947, p. 412, pl. 1) because he follows the widely accepted usage of referring the Sierra Nevada granitic rocks to the Jurassic. A wider range in age of granitic rocks in the southern Death Valley region is advocated by L. F. Noble (1941, p. 954); the rocks probably represent two or more widely separated periods of intrusion, as some granitic rock in the Virgin Spring area (about 65 miles southeast of the Quartz Spring area) may be Tertiary (Noble, 1941, p. 963). In reviewing the age of plutonic rocks in California, Larsen (1948, p. 136) indicates that those in northern California, southern California, and Baja California are related to each other; and for the age of the batholith in southern California Larsen favors Early Cretaceous, rather than

[5] Quartz-monzonite in this report means a granular igneous rock in which potash feldspar is at least 35 percent but not more than 65 percent of the total feldspar, and quartz is at least 5 percent of the felsic minerals. Adamellite as defined by Johannsen (1932, pp. 308-309) is synonymous and preferable but much less current in mining country.

the very late Jurassic age assigned to the northern rocks, or the early Late Cretaceous age assigned to those in Baja California. The Early Cretaceous supports Knopf's usage for the Inyo Range and consequently the preference herein for Cretaceous(?) as the age of the intrusive rocks in the Quartz Spring area.

Petrography

The texture of the rocks is varied. It ranges from nonporphyritic through many combinations of porphyritic, and the grain-size ranges from 90 millimeters in syenite-pegmatite to the smallest common size of 0.05 millimeter in the groundmass of monzonite-porphyry. In the porphyritic rocks the volume of phenocrysts ranges from 20 to 60 percent, and some of the phenocrysts are as much as 70 millimeters long. Most of these textural varieties are also trachytoid; that is, the predominant elongate and tabular feldspar grains have a parallel or subparallel arrangement.

The composition also varies greatly, ranging in proportion of mafic minerals from slightly less than 3 percent in leucosyenite to 42 percent in the groundmass of porphyritic aegirine-augite syenite; and ranging in silica saturation from undersaturated nepheline-syenite, through saturated syenite, to oversaturated aplite. The quantity of quartz-bearing rock is greatly subordinate to that of saturated and undersaturated rocks. Pegmatitic diaschists contain no quartz. A characteristic of composition that the rocks have in common is the relative abundance of soda, which is shown by the large proportion of albite in the ubiquitous microperthite, by aegirine-augite, and in some rocks, by nepheline.

Trachytoid Leucosyenite. The most abundant intrusive rock in the Quartz Spring area is trachytoid leucosyenite.[6] It occurs in sills and dikes about half a mile or more northeast of Burro Spring. Much of it is in contact with the Rest Spring shale or the silty calcareous Perdido formation. The typical trachytoid leucosyenite (3010)[7] is grayish orange (10 YR 7/4)[8] and only slightly graver where it is freshest. Most of the grains are subhedral microperthite 3 to 5 millimeters long and 1 millimeter to 2 millimeters wide in a subparallel arrangement. A micrometric analysis along 161 millimeters shows that about 45 percent of the rock is orthoclase, 52 percent is albite, and 3 percent is accessory and secondary minerals. The albite and orthoclase are combined in microperthite, which thus constitutes 97 percent of the leucosyenite. Albite makes up a large part of some microperthite grains, leaving ragged islands of orthoclase. Most of the albite appears to be a replacement of orthoclase rather than a product of exsolution. The accessory and secondary minerals are biotite, aegirine-augite, magnetite, sphene, melanite, chlorite, muscovite, and calcite. A little of the biotite is a deuteric alteration of pyroxene, and some is in clots of melanite, sphene, aegirine-augite, and magnetite. Chlorite altered some of the biotite, and muscovite replaced a very little of the microperthite.

Muscovite leucosyenite (3011) is one of the variants of the trachytoid leucosyenite. Where it crops out about $1\frac{1}{2}$ miles east-northeast of Burro Spring, it is a grayish-yellow (5 Y 8/4) coarse-grained rock of conspicuously trachytoid fabric. It consists of microperthite, a little albite not intergrown with orthoclase, and muscovite. Most of the rock is made up of highly albitized orthoclase in grains 10 to 20 millimeters long, 5 to 10 millimeters wide, and 1 millimeter to 2 millimeters thick. Clusters of muscovite fill interstices among the closely packed feldspar grains. Only in the most favorable places is the interstitial muscovite in pockets as much as 3 millimeters thick, and in most places it is less than 1 millimeter or absent. The diameters of the pockets in the plane of the trachytoid fabric are as much as 5 millimeters; the pockets are connected, however, in an irregular network. In some places the muscovite forms clusters having a subhexagonal outline within the microperthite, where it may be a replacement of early euhedral nepheline.

Very coarse-grained leucosyenite (3012) is a nontrachytoid variant that crops out on the ridge $2\frac{1}{4}$ miles northeast of Burro Spring. It is a medium light gray (N 6) rock of microperthite, some of which has a bluish iridescence. The accessory minerals were estimated to be less than 1 percent of the volume. The microperthite grains are on the order of 20 millimeters long and 5 millimeters wide, whereas the mafic grains are commonly 1 millimeter to 2 millimeters in diameter. The proportion and coarseness of the microperthitic albite varies greatly from grain to grain of orthoclase. Some of the intergrowth is very fine. A small quantity of albite forms separate grains, some of which are interstitial, whereas others are randomly oriented inclusions in the orthoclase, distinct from the albite of the microperthite. The accessory minerals are biotite, partly altered to chlorite, aegirine-augite, sphene and ilmenite, apatite, magnetite, and muscovite. A little melanite is visible in the hand specimen.

In the porphyritic leucocratic rocks the proportions of phenocrysts and groundmass are widely different. The extreme low in the proportion of phenocrysts is a trachytoid porphyritic syenite (3021), which is exposed on the southeastern part of a spur nearly 3 miles east-northeast of Burro Spring. The yellowish-gray (5 Y 6/2) groundmass constitutes about 80 percent of the volume. Light bluish gray (5 B 6/1) Carlsbad twins of orthoclase form well-alined phenocrysts about 70 millimeters long and 12 millimeters thick, in a groundmass of feldspar grains, many of which are about 7 millimeters long, and a few mafic grains of about 1 millimeter. The orthoclase of the phenocrysts is incipiently microperthitic, but in the groundmass it has a high percentage of intergrown albite. Andesine, which is abundant in the groundmass, is rimmed with albite. Accessory sphene, apatite, and magnetite are more abundant and commonly in larger grains than the biotite and amphibole.

The other extreme among the porphyritic rocks is a trachytoid porphyry of altered nepheline-syenite (3022) (fig. 13), which crops out on a hill 2 miles N. 80° E. of Burro Spring. The groundmass constitutes as little as 40 percent of the volume, estimated from a measurement of 428 millimeters normal to the trachytoid fabric in hand specimens. The pale grayish orange (10 YR 8/4) rock consists of large tabular euhedral microperthite in a fine-grained groundmass. The tabular phenocrysts, which lie roughly parallel, in places are so closely packed that they touch, but in other places in the same hand specimen they

[6] Syenite, as used in this report, is a granular igneous rock in which potash feldspar (including intergrown albite or microperthite) is more than 65 percent of the total feldspar, and quartz is less than 5 percent of the felsic minerals. The prefix leuco- is used for rocks that contain less than 5 percent dark minerals.

[7] Numbers refer to specimens at Stanford University.

[8] Symbols and names of colors are according to the "Rock-Color Chart," by E. N. Goddard and others, National Research Council, 1948.

FIGURE 13. Trachytoid porphyry of altered nepheline-syenite. An extreme among the porphyritic rocks, showing the closest packing of large microperthitic orthoclase phenocrysts. The variation in color of the groundmass is from weathering. Approximate scale.

are well isolated in the groundmass. The largest phenocrysts are as much as 70 by 40 by 8 millimeters, but most are about 50 by 25 by 5 millimeters; average grains of the groundmass are less than 1 millimeter. The direction of the trachytoid orientation changes within short distances. Some of the microperthite has clear cores of orthoclase. The groundmass contains microperthite, and clusters of muscovite and calcite. Some of the clusters are subhexagonal in outline and are probably altered feldspathoid. All the mafic minerals, in accessory amounts, also were altered to finer-grained aggregates of iron oxides and calcite.

Melanite nepheline-syenite. Although of very limited occurrence in a spur 2½ miles N. of 70° E. of Burro Spring, melanite nepheline-syenite (3013) is noteworthy because it contains the only coarse-grained, fresh nepheline that has been seen in the area. When found in 1937, nepheline had not yet been reported as occurring in place in California (Murdoch and Webb, 1948, p. 22). This occurrence of nepheline in California is far from the cordilleran zone of alkalic rocks.

The nepheline-syenite is similar to the preceding leucosyenite (3012) and to other melanite-bearing syenites in the Ubehebe Peak quadrangle, except that it contains a slightly greater quantity of dark minerals and some interstitial nepheline. It is light gray (N 7) or medium light gray (N 6), spotted by the dark garnet. Some of the feldspar iridesces very pale blue (5 B 8/2). Weathering has little effect on the color of the rock, but it pits the surface by decomposing the interstitial nepheline. The texture is coarse-grained hypidiomorphic, varying abruptly in grain size. Most tabular grains of microperthite are 10 to 20 millimeters long and few are more than 40 millimeters long. Exceptionally large nepheline grains are 20 millimeters long, whereas common sizes are 2 to 5 millimeters. Grains of melanite range in diameter from less than 1 millimeter to about 10 millimeters where elongate or possibly in aggregates; most are about 3 millimeters.

The coarse texture forestalled determining adequately in the thin sections the proportions of minerals. A megascopic analysis based on a linear measurement of 245 centimeters indicates that the specimen consists of 81 percent alkalic feldspar, 16 percent nepheline (including zeolitized parts), and 3 percent melanite. Accessory biotite, augite, and magnetite, as seen in thin section, constitute a small fraction of 1 percent and are included with melanite in the mode.

Most of the feldspar is microperthite, in which albite occurs in many degrees of coarseness, starting exceedingly fine, and as several types of intergrowth, depending on size, shape, and distribution. The proportion of albite is notably different from grain to grain, as it has replaced more than half of some grains, leaving irregular patches of orthoclase, and in other grains albite is scarcely present. Some albite (about $Ab_{92}An_{08}$), not intergrown with orthoclase, forms large separate grains. Clear orthoclase is moderately sodic, roughly $Or_{70}Ab_{30}$, which is shown by the extinction angle of 9° between X and (001) in cleavage fragment (010) normal to Z (Winchell, 1951, fig. 190).

Fresh nepheline in the hand specimen is pale grayish orange (10 YR 7/2) and has a greasy luster. The powder gelatinizes in hydrochloric acid. It is negative uniaxial, of low relief in balsam, and of weak birefringence. Some of the nepheline has altered to zeolites. In thin section the zeolite aggregates having hexagonal outline within microperthite may be altered nepheline, but the dodecahedral shape of pits of the same size (about 0.5 millimeter) on weathered surfaces suggests that the altered mineral may have been sodalite.

The black or brownish garnet in this rock is called melanite because of the color and the typical occurrence in nepheline-syenite and other syenitic rocks. The color in thin section magnified 20 times (a daylight microscope lamp was used when determining colors in thin sections) ranges from light olive gray (5 Y 6/1) to dusky yellow (5 Y 6/4). The garnet is euhedral or subhedral, isotropic, and high in relief. A similar dark garnet from the Ubehebe Peak quadrangle, according to Jewell J. Glass of the U. S. Geological Survey (written communication, November 1950), is melanite: it has an index of refraction of 1.86 and in a qualitative test showed some titanium. In some syenite of the Quartz Spring area the garnet is associated with abundant accessory sphene and some leucoxene-rimmed ilmenite, a titaniferous environment.

The chemical analysis and norm of a specimen of this melanite nepheline-syenite (3013) are given with the

Analysis, norm, and mode of melanite nepheline-syenite (3013) from the Quartz Spring area.

Analysis W. H. Herdsman, analyst		Norm		Mode (Percent volume)	
SiO_2	59.14	or	37.17	Alkalic feldspar	81
Al_2O_3	21.72	ab	41.61	Nepheline (fresh and altered)	16
Fe_2O_3	0.98	an	11.93	Melanite	3
FeO	0.71	ne	4.72		
MgO	0.94	c	0.76		
CaO	2.42	ol	2.70		
Na_2O	5.69	mt	0.83		
K_2O	6.28	il	0.28		
H_2O+	1.54				
H_2O-	0.32				
TiO_2	0.12				
P_2O_5	Trace				
MnO	Trace				
CO_2	Trace				
	99.86				

mode in the accompanying table. The norm differs from the mode in the percentage of nepheline and in the proportion of anorthite in the plagioclase. Nepheline is only about 5 percent (weight) in the norm, whereas in the mode it is about 16 percent (volume). The norm makes no provision for melanite, which may account for the more calcic plagioclase in the norm ($Ab_{78}An_{22}$) than in the mode ($Ab_{92}An_{08}$).

A melanite syenite (3014) that is finer grained and somewhat darker contains large patches of natrolite, which probably is zeolitized nepheline. The mafic minerals are augite and green biotite. Sphene and magnetite are accessory.

Aegirine-augite Monzonite and Monzonite-Porphyry. Aegirine-augite monzonite (3015), which crops out on the hill three-quarters of a mile north of Burro Spring and south of the leucosyenite (3010) is one of the most abundant of the less leucocratic rocks. It also is trachytoid, but lacking the orange tint of the leucosyenite, it is medium light gray (N 6). Slender feldspar grains are commonly 2 to 5 millimeters long and many of the aegirine-augite grains in the hand specimen are between 1 millimeter and 2 millimeters, although in thin section a more usual size is about 0.5 millimeter. Microperthite and plagioclase (near the division between oligoclase and andesine) are in nearly equal proportions. Micromeasurements along 107 millimeters gave the following volume percentages:

Microperthite	48
Plagioclase	44
Aegirine-augite	6
Accessories	2

The accessory minerals are sphene, magnetite, biotite, and apatite. Some anhedral magnetite is closely associated with the aegirine-augite. Near aplitic dikes the aegirine-augite monzonite is somewhat epidotized and sericitized.

Aegirine-augite monzonite-porphyry (3017) crops out 2½ miles northeast of Burro Spring. The rock is medium light gray (N 6) and weathers light or pale brown (5 YR 6/4 or 5 YR 5/2). Phenocrysts of microperthite are 20 to 30 millimeters long and 10 to 15 millimeters wide; another generation of microperthite and plagioclase phenocrysts, as measured in thin section, range in length from about 0.5 millimeter to 1.5 millimeters; and aegirine-augite crystals are seriate up to 1 millimeter long. The groundmass of roughly equal quantities of orthoclase and plagioclase is hypidiomorphic in grains generally about 0.05 millimeter long. The plagioclase in phenocrysts is andesine ($Ab_{58}An_{42}$), except in rims, whereas in the groundmass it is probably oligoclase. In a micromeasurement of 100 millimeters, 9 percent of the volume is aegirine-augite. Euhedral magnetite, sphene, and apatite together form much less than 1 percent of the rock.

Aegirine-augite Syenodiorite. An increase in the proportion of plagioclase forms aegirine-augite syenodiorite (3018),[9] which occurs locally near the melanite nepheline-syenite (3013), close to marble. The texture is medium- or fine-grained granitic, which in thin sections appears moderately trachytoid. In hand specimens the largest grains of feldspar commonly are 5 millimeters long, but in the thin sections few grains are 1.5 millimeters and most are 0.5 to 1.0 millimeter long. Many of the mafic grains are about 0.3 millimeter in diameter, and where elongate, about 1.0 millimeter in length; however, sphene is as much as 2.5 millimeters long.

The mineral composition of a specimen is shown approximately by the following micrometric analysis along lines aggregating 86 millimeters:

	Percent volume
Orthoclase (variably microperthitic)	24
Andesine	53
Aegirine-augite	14
Hastingsite	4
Magnetite	3
Sphene	1
Melanite	1

Some of the orthoclase is nearly free of albite intergrowth but some is highly perthitic. The andesine ($Ab_{67}An_{33}$) tends to form elongate grains approximately the same size as the orthoclase grains. The alkalic feldspar is 31 percent of total feldspar, making the rock syenodiorite. Pleochroic green aegirine-augite is rimmed by more strongly pleochroic darker green to bluish green hastingsite, which is described more fully under the altered nepheline syenite (3019) that follows. Sphene and melanite, although accessory, are conspicuous. Biotite and apatite are scarce.

Hastingsite Nepheline(?)-Syenite. Another darker rock is hastingsite nepheline(?)-syenite (3019), in which the probable nepheline has been altered to natrolite. It occurs locally, near the contact with marble at the head of the canyon about 2½ miles east-northeast of Burro Spring. The texture is hypidiomorphic medium grained. A micrometric analysis based on a traverse 118 millimeters long gave the following mineral composition:

	Percent volume
Microperthite	60
Natrolite after nepheline(?)	10
Hastingsite	11
Augite	8
Biotite	6
Melanite	4
Apatite	1

There are also a few crystals of sphene and fewer of zircon. Some of the microperthite contains a large amount of albite, but as in other rocks of the area, the proportions and form vary from grain to grain. No fresh nepheline remains in the thin sections; however, natrolite in well-defined masses is considered to be an alteration of nepheline. The hexagonal outline in section of some of the masses may be the shape of original euhedral nepheline, or possibly of sodalite, as suggested for the previously described melanite nepheline-syenite (3013).

The hastingsite, which in thin section shows good amphibole cleavage, has a small axial angle, large maximum extinction angle ($c \wedge Z = 35°$), weak birefringence, is optically negative and strongly pleochroic as follows:

X = dark greenish yellow (10 Y 6/6)
Y = dusky yellowish green (10 GY 3/2)
Z = grayish green (5 G 5/2)
Absorption = Y>Z>X

The characteristics that distinguish this hastingsite from hornblende are the distinctively small axial angle, large extinction angle, and strong pleochroism that includes grayish ("bluish") green. The same optical properties were emphasized in the first descriptions of hastingsite from the type locality in Hastings County, Ontario

[9] It is called syenodiorite because it is a quartz-free granular igneous rock in which potash feldspar is at least 5 percent but not as much as 35 percent of the total feldspar and the plagioclase is more sodic than labradorite.

(Adams, 1894, p. 13; Adams and Harrington, 1896, pp. 210-211; Graham, 1909, pp. 540-543). Later, recognizing that the properties of hastingsite vary considerably, Quensel (1941, p. 152) redefined hastingsite to include ". . . hornblende with small axial angle, with a probably indefinite position of the axial plane . . . , low birefringence, . . . with Y or Z lying nearest *c*, forming large extinction angles, and with strong axial dispersion." Chayes (1942, p. 477), on measuring the optical properties of some amphiboles from Hastings County, also recognizes variations of the optical properties of the amphiboles that include "hastingsite?" but concludes ". . . that there is very little basis for a sharp distinction between the common deep green hornblende of the area and the so-called hastingsite." In some usage of the term the small axial angle and the other originally distinctive optical properties have been lost in the complexities of systematizing the amphiboles; other usage has continued to emphasize the original distinctive properties. Hastingsite, even though its distinctive optical properties may be gradational with those of common hornblende, is used in this report because it is descriptively useful for amphibole that combines these more extreme properties and occurs characteristically in alkalic rocks. The hastingsite of the Kruger alkaline syenites in British Colombia, as described by Campbell (1939, p. 532), and of the Oroville malignite in Washington (Krauskopf 1941, pp. 25, 27), is similar to the hastingsite of the Quartz Spring area.

The biotite in the hastingsite nepheline(?)-syenite is pleochroic in similar but much paler colors and likewise has small axial angle, but it is distinguished by the cleavage, birefringence, and clearly lower relief. It is the third in a denteric reaction series from augite through hastingsite to biotite. Nevertheless, large proportions of the three minerals form grains that are free of the others.

The darkest rock is a mesotype porphyritic altered nepheline-syenite (3020), which is nearly 35 percent mafic and conspicuously trachytoid. Only a small quantity occurs near the last rock described (3019). Phenocrysts of orthoclase commonly are about 15 millimeters long and 5 millimeters wide. They enclose small grains of mafic and accessory minerals. The dark gray (N 3) groundmass, according to a megascopic measurement 650 millimeters long, constitutes 82 percent of the rock's volume. Grains in the groundmass commonly range from 0.2 to 1.0 millimeter, except orthoclase grains, which commonly are about 0.5 by 2.5 millimeters. Phenocrysts and grains of the groundmass are well alined.

The approximate mineral composition of the groundmass, calculated from a microscope traverse 90 millimeters long, follows:

	Percent volume
Orthoclase	52
Altered nepheline	5
Hastingsite and aegirine-augite	33
Melanite	8
Biotite, apatite, sphene, magnetite	2

The orthoclase is slightly microperthitic. Fine-grained masses of zeolites and muscovite are considered to be altered nepheline. There is somewhat more hastingsite than aegirine-augite, and some of it poikilitically encloses euhedral aegirine-augite. The hastingsite is an amphibole similar to that of the hastingsite nepheline-syenite (3019) in that the axial angle is small, the birefringence weak, and the extinction angle ($c \wedge Z = 30°$) is large for an amphibole, but the similar pleochroism is slightly more olive, as follows:

X = light olive (10 Y 5/4)
Y = grayish olive green (5 GY 3/2)
Z = grayish green (5 G 5/2)
Absorption = Y>Z>X

The aegirine-augite has the optical characteristics of pyroxene, a maximum extinction angle of 67° between *c* and Z, and is pleochroic from dusky yellow (5 Y 6/4) to pale blue green (5 BG 6/2). Some has a colorless augite core, showing a smaller extinction angle. Isotropic melanite in thin section is light brown (5 YR 5/4). Some of the accessory apatite is unusually large.

Syenite Pegmatite. Pegmatitic and aplitic rocks also show an alkalic affinity. The pegmatite contains no quartz, whereas many of the aplitic rocks do have quartz. A syenite pegmatite (3023), which occurs in a small irregular dike about 2½ miles N. 60° E. of Burro Spring, is the coarsest rock found in the area. Yellowish gray (5 Y 8/1) anhedral microperthite crystals, oriented at random, are commonly 70 by 50 by 5 millimeters and are as much as 80 millimeters long. The microperthite contains a large proportion of albite, and it is slightly replaced by muscovite and calcite. Spaces between the large microperthite grains are filled with finely granular muscovite, calcite, less albite, both euhedral and anhedral magnetite, and very little pyrite. In syenite near the pegmatite there are some veinlets of blue crocidolite.

Nordmarkite. Quartz-bearing alkalic leucosyenite, or nordmarkite (3024), has a medium-grained hypidiomorphic texture, which contrasts sharply with the nearby trachytoid coarsely porphyritic altered nepheline-syenite (3022). Many grains in the nordmarkite are elongate microperthite as much as 5 millimeters long and 2 millimeters wide, although the more equidimensional grains are about 1.0 millimeter across. Most mafic grains are 0.5 millimeter or somewhat less, and a few of the irregular interstitial quartz grains are as much as 0.5 millimeter in the longest dimension.

The mineral composition of the nordmarkite is shown by the following micrometric analysis based on a measurement 146 millimeters long:

	Percent volume
Microperthite	76
Plagioclase (not in microperthite)	16
Quartz	3
Aegirine-augite	5—

Sphene, apatite, and magnetite together form much less than 1 percent; of these sphene is the least scarce. The microperthite contains a large proportion of albite in patches, veins, and rims; in some grains the orthoclase is subordinate. The quartz is clearly interstitial, sharply angular in outline between faces of microperthite crystals, which it does not transect or replace. The quartz, though late in the sequence of crystallization, is not hydrothermal. Aegirine-augite is accessory but it is conspicuous because of the brilliant greens in thin section and the peppery aspect in the hand specimen. The color and the large extinction angle ($c \wedge Z = 77°$) indicate that it is high in aegirine.

Aplites. The finer-grained hypidiomorphic, leucocratic, largely quartz-bearing rocks that occur in dikes through

the other intrusive rocks are aplites in the broadest sense of the term but not in the stricter sense that requires a saccharoidal texture and always quartz. The close genetic relationship of the aplites to the coarser-grained alkalic rocks is indicated by the prevalence of albite as a separate mineral in some or as an abundant constituent of microperthite in most, and by a little aegirine-augite. In the proportions between the feldspars some of the aplites are equivalent to the coarser-grained syenite, and others to the coarser-grained monzonite. The principal difference is the oversaturation with silica.

Granitic aplite (3026) is closely associated with the abundant trachytoid leucosyenite (3010) on the eastern side of the mountain about a mile north-northeast of Burro Spring. The granitic aplite, which more precisely is fine-grained leucogranite, is yellowish gray (5 Y 7/2) and has a few brown specks as if from weathered pyrite. The texture is fine-grained hypidiomorphic, in which most grains are about a millimeter or somewhat less in diameter, although microperthite grains are seriate up to 2.5 millimeters, and interstitial quartz grains are commonly about 0.5 millimeter. The mineral composition, as derived from a micrometric measurement 221 millimeters long, consists of 83 percent microperthite, 16 percent quartz, and somewhat more than 1 percent iron oxides and apatite. The microperthite contains a large proportion of albite, which replaces also a few grains of more calcic plagioclase, which were counted with the microperthite.

Another granitic aplite (3027), or fine-grained leucogranite, is associated with the muscovite leucosyenite (3011). The aplite is medium light gray (N 6), becoming light olive gray (5 Y 6/1) where specked with limonite. The texture is fine-grained hypidiomorphic, consisting of subhedral microperthite grains mostly between 0.5 and 1.0 millimeter except those that are elongate as much as 1.5 millimeters, of anhedral plagioclase grains 0.5 millimeter or less, and of anhedral quartz mostly about 1 millimeter across.

The mineral constituents are predominant microperthite, abundant quartz, and less plagioclase in distinct grains that are not part of the microperthite. The sparse accessory minerals, aggregating a small fraction of 1 percent, include aegirine-augite, sphene, pyrite largely weathered to hematite and limonite, and violet fluorite. The proportions of the constituents are shown in the following micrometric analysis from a traverse 72 millimeters long:

	Percent volume
Microperthite	51
Oligoclase	21
Quartz	28

The microperthite, 71 percent of total feldspars, contains a large proportion of albite, which rims and irregularly patches the microperthite and predominates in some grains. Oligoclase about $Ab_{84}An_{16}$, as determined by the indices of refraction of cleavage fragments, makes fine-grained aggregates among the microperthite grains, and a little in microperthite forms inclusions without the systematic orientation of the perthite albite. Some of the quartz is interstitial, having straight edges in contact with microperthite faces, but some transects microperthite. Individual grains under crossed nicols show a faint mosaic. The interstitial quartz is considered to be an original constituent of the rock, but some of the other quartz may be a replacement formed during a stage when pyrite and fluorite were added.

Quartz-monzonitic aplite (3016), or fine-grained albite leuco-quartz-monzonite forms dikes in aegirine-augite monzonite-porphyry (3017) 2½ miles northeast of Burro Spring. In the hand specimen it is very light brownish gray (5 YR 7/1) weathering light brown (5 YR 6/4), and appears saccharoidal from the abundant equidimensional anhedral quartz. The texture, however, as shown by thin section is hypidiomorphic rather than saccharoidal, and consists of grains commonly 0.5 to 1.0 millimeter across. The mineral composition of a specimen is shown by the following micrometric analysis based on a traverse 170 millimeters long:

	Percent volume
Orthoclase	35
Albite	39
Quartz	26

The orthoclase, some of which is incipiently microperthitic, is 47 percent of the total volume of feldspars, making the rock quartz-monzonitic. The albite is an original constituent of the rock, the first grains having crystallized before some of the quartz. A very small quantity of accessory minerals consist of magnetite and biotite. Some sericite and muscovite are secondary.

Origin of the Alkalic Rocks

The origin of undersaturated alkalic rocks is a controversial subject that has been extensively treated in geologic literature and well summarized in petrologies. From this background, especially the writings of Daly (1933, pp. 482-544) and Shand (1949, pp. 77-85, 312-331), the following explanation seems reasonable for the origin of the alkalic rocks of the Quartz Spring area. At a late stage in the crystallization of a quartz-monzonite batholith, exposed beyond the area, small masses of residual magma were injected relatively far into predominantly carbonate rock, which desilicated the small masses as they passed through the limestone and dolomite, producing the bulk of the syenite. A small part was desilicated sufficiently to produce nepheline-syenite. Another small part, in dikes through previously solidified syenite, was protected from the desilicating carbonate rock and produced the normal quartz in aplite. All these intrusive rocks were altered to a varied extent by highly sodic emanations.

The emplacement of at least some of the intrusive rock was by injection. Three-dimensional exposures in gulches about 500 feet deep show well that thick dikes and sills crumpled back incompetent beds and bowed the more competent beds. A wedging effect together with marginal crumpling, made by a large sill, is exposed near the canyon junction in the northeastern corner of the area. In massive country rock, as along the eastern crest of the Panamint Range, the irregular intrusions were much less obviously injected, and they may have been controlled by irregular joints.

Piecemeal stoping and assimilation seem in this area to be minor results of the forceful injection and not the main processes of emplacement. Some blocks of the country rock, both marble and a little quartzite, are caught in the syenitic rock near the borders, as exposed in O'Brien Canyon (see pl. 1), and demonstrate that piecemeal stoping locally took place. Some small inclusions of

quartzite more than 100 feet from an exposed contact probably were plucked from a sill's floor, which is exposed farther down the canyon. Within small areas near contacts limestone xenoliths exhibit an arrested series in digestion. Also the presence of melanite, as in the fresh nepheline-syenite (3013), according to Shand (1949, p. 307) may be used to prove assimilation of some limestone. The small total amount of stoping and assimilation at the places now exposed is indicated by the low proportion of minerals rich in calcium and magnesium in the rocks as a whole, and by the leucocratic rocks that are sufficiently well exposed in small masses to show that crystal settling does not account for the scarcity of heavier minerals. It thus seems that assimilation of carbonates where the intrusive rocks solidified at the places now exposed in the Quartz Spring area does not adequately account for the low content of silica but assimilation may have been more effective during transit.

The percentage of silica was decreased also by reaction with the carbonate wall rock; silica was contributed to calcium and magnesium silicates in the surrounding pyrometasomatic zone. The effectiveness of this method is difficult to determine, particularly at the final location of the rocks. There are zones of silicated marble around the syenitic rocks, but in the Ubehebe Peak quadrangle there are some broader zones in contact with quartz-monzonite in much larger masses. The large masses beyond the area more successfully maintained an equilibrium between the principal part and the borders that reacted with marble; whereas small masses isolated in marble in the Quartz Spring area did not maintain equilibrium with the siliceous source.

The ultimate effectiveness of the desilication by carbonates probably was contingent on the relatively small volume of the Quartz Spring syenitic rocks and their isolation from the magmatic source. The passage of small intrusive masses from the quartz-monzonite parent to isolated places in marble provided a good opportunity for reaction with limestone and for inequilibrium with the siliceous parent. There is no evidence to show, however, which method of reaction was more effective in reducing the proportion of silica during the passage, desilication by assimilating carbonate rock or by losing silica through additive contact-metamorphism of the carbonate country rock. Irrespective of which process was dominant and where it took place, this occurrence emphasizes again the stressing by Daly and Shand of the close relationship of limestone with desilicated feldspathic rock. The proportion of melanite-bearing syenite and nepheline-syenite is small relative to all the syenitic rocks of the area, and in turn the proportion of syenitic rocks with respect to the quartz-monzonite exposed in the region is equally small or smaller. The geologic map, structure sections, and particularly the stratigraphy of the Quartz Spring area demonstrate the abundance of limestone and dolomite in the environment of the silica-poor intrusive rocks.

The alkalic nature of the rocks is here partly an original characteristic and partly a late acquisition (see Ball, 1907, pp. 206-208). The normal late differentiates around the margins of quartz-monzonite in the Ubehebe Peak quadrangle are pegmatites and aplites rich in orthoclase and albite and poor in mafic minerals. The Quartz Spring rocks originally were similar to these but for the loss of silica, as orthoclase and microperthite formed much of the original rocks. At least some of the orthoclase is moderately sodic, about $K_{70}Ab_{30}$ (3013), and probably a large part was originally microperthitic. Some of the albite appears to be primary. Euhedral feldspathoids, as inclusions in microperthite and as interstitial grains, crystallized early. Then soda-rich solutions greatly increased the quantity of albite in microperthite, rimming many grains, leaving isolated ragged patches of orthoclase in some, and entirely replacing others, forming an aggregate of completely oriented fine-grained albite within the outline of the grain (see Anderson, 1937, pp. 59-61). Albite formed replacement rims on more calcic plagioclase and in some grains left only irregular cores. The sodic solutions reacted with augite to form coronas or entire grains of aegirine-augite. The amphibole, some of which is a deuteric alteration of pyroxene, is hastingsite. The active role of late solutions is shown further by muscovite replacement of some feldspathoid, orthoclase, and biotite, and by traces of pyrite and fluorite.

In summary, the regional distribution of saturated and undersaturated rocks in relation to the distribution of oversaturated quartz-monzonite and carbonate rocks favors the theory of desilication by the carbonate rocks. Syenite was produced from small masses of a somewhat pegmatitic differentiate from quartz-monzonite, by desilication on passing through Paleozoic limestones and dolomites, where virtually no circulation with the siliceous parent magma impeded equilibrium. The small quantity of nepheline-syenite formed where the desilication was most effective. The pegmatitic aspects, the trace of fluorite, and the deuteric addition of soda to the minerals support the suggestion that the alkalic rocks of the Quartz Spring area were produced during the late stage of crystallization of a residual magma containing abundant fugitive constituents, which were rich in soda.

ECONOMIC GEOLOGY *

To date, the mineral production of the Quartz Spring area has been confined to a few hundred tons of tremolite-bearing altered carbonate rock obtained on the northwest flank of Whitetop Mountain, and marketed under the commercial name asbestos. In an area immediately east and south of the upper part of O'Brien Canyon siliceous veins, containing irregularly distributed copper minerals and fluorite, have been prospected but not worked commercially. Limestone and dolomite are widely exposed, but as commercial materials they have attracted little interest because of the lack of rail facilities and the distance to industrial centers.

The only reported occurrence of nepheline syenite in California is in the Quartz Spring area. White-burning nepheline syenite is widely used in the ceramic industry in the production of whiteware for which its fluxing properties are desirable. Preliminary tests were made in the University of California Ceramics Laboratory to determine the firing color of the Quartz Spring material. Colors resulting from the firing of six random samples ranged from light buff to dark brown because of the presence of ferruginous minerals. The tests indicate that the material tested could not be substituted for nepheline syenite now used in whiteware. However it is possible that ceramic uses with less rigid color requirements could be found for this material. Further investigation is necessary to determine the size, quality, and accessibility of the syenite bodies.

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No minerals of commercial interest have yet been noted in the contact-metamorphic zones that, in several places, have developed in carbonate strata near syenite contacts. Search for tungsten minerals, in particular, yielded negative results. A genetic relation between syenite, the altered carbonate rock, and the siliceous veins bearing copper and fluorite, is suggested by the restriction of all three to the northeast corner of the accompanying map.

Copper and Fluorite Deposits. Most of the siliceous, copper- and fluorite-bearing veins of the O'Brien Canyon area are contained in seven or more claims which in 1917 were located by J. F. Berkey as the Silver Crown group and are still rather well marked. The deposits previously had been prospected as early as 1912 and have since been relocated several times under various names.

The veins lie within a north-trending belt of carbonate strata (Tin Mountain limestone and Perdido formation) bordered on the west, south, and east by syenite and associated intrusive rocks. The veins range in length from a few feet to as much as 700 feet. Some are locally as much as 25 feet wide, but most average less than 5 feet in width. Most strike northwest and dip moderately to steeply, ordinarily to the northeast.

Copper minerals, in quantity ranging from a trace to several percent of malachite, azurite, chrysocolla and bornite, are very erratic in distribution. The minerals, together with iron oxides, are disseminated through the veins and also occur as fracture-fillings and smears on fracture surfaces. For most of their lengths the veins are nearly barren of other minerals. The higher-grade, copper-bearing masses are not large, rarely exceeding 2 or 3 feet in thickness and 20 feet in diameter.

The fluorite exists as apple-green or violet transparent to subtranslucent grains as much as 3 inches in diameter. It occurs in veinlets and in irregular aggregates as much as 3 feet in diameter. It is generally most abundant in the copper-bearing parts of the veins, but forms not more than a few percent of the volume of such parts. Some of the fluorite forms veinlets and small pods and lenses in the carbonate sediments and is not associated with silica.

Workings in these copper and fluorite deposits consist mainly of shallow pits and cuts. Three of the veins, however, have been prospected by limited underground workings shown by the adit and shaft symbols on the accompanying map. The adit, about 75 feet long and trending southeastward, was driven in an unsuccessful attempt to intersect a small copper-bearing vein. The vein, as exposed on the surface, is about 30 feet long, 3 feet in maximum width and dips steeply eastward. It is a vertical distance of about 70 feet above the adit level. The adit is entirely in limestone.

Of the two shafts, the more westerly is on a copper- and fluorite-brearing siliceous vein about 100 feet long, 8 feet in maximum width and striking west-northwest and dipping gently north-northeast. The incline is but 20 feet long, and follows the vein down-dip at an angle of about 30°.

The other shaft has been sunk on the most strongly mineralized outcrop of a vein about 200 feet long and 5 feet in average width. The vein strikes northwest and dips about 60 degrees southwest; the shaft follows it down-dip for a slope distance of about 35 feet.

Deposits of Tremolite-Bearing Rock. Although small amounts of long fiber chrysotile asbestos are exposed in several prospect pits none has been mined. The material mined and sold as asbestos is an altered carbonate rock which contains varying percentages of tremolite in short unoriented fibers. Shortness of fiber and presence of carbonate impurities make this material unsuitable as filter asbestos. It is marketed as a filler and is used chiefly in building plaster.

In recent years 22 claims have been located by C. W. Lawrence, 1408 Grace Street, Bakersfield, on deposits of altered carbonate rock discontinuously distributed along the East Crest from the north side of Whitetop Mountain northward for at least 1½ miles. Of the known deposits, the larger lie along the mountain's northwestern spur. They are the more thoroughly explored and the site of commercial operations to date. All are accessible by a road from the canyon west of East Crest. The present lessee and operator is Huntley Industrial Minerals Inc., Bishop.

Most of the known material of commercial interest is in four lenses ranging from about 150 feet to 400 feet long and from 15 to 50 feet in maximum thickness. Each appears to strike east to northeast and to dip moderately north to northwest. Each has altered from carbonate rocks probably of the Ely Springs dolomite.

Operations to date have centered about the largest and most completely altered lens which lies athwart the ridge crest, strikes east-northeast, and dips about 25° north-northwest beneath a small knob. A dolomite overburden on the knob does not appear to be more than 30 feet thick over most of the lens.

The lens is predominantly very white, fine-grained layered rock composed mostly of magnesian silicate minerals, calcite and dolomite. In an inspection of several thin sections of the rock, tremolite, talc, and a mineral tentatively identified as serpentine were the silicates noted. The rock ranges from friable to very tough and from blocky to schistose.

Most of the rock consists of grains less than 0.1 millimeter in maximum dimension. Carbonate material appears to comprise from one-quarter to one-half of the rock's volume. It is rather evenly disseminated, but also occurs as irregular nodules and lenses several inches long. The tremolite occurs in elongate grains which characteristically comprise plumose aggregates. These aggregates commonly lie normal to the layering. In other places they parallel the layering and form a schistose rock. Radiating patterns are also common. Talc, probably the least abundant of the major constituents, is irregularly disseminated through the rock, and is probably a replacement both of carbonate material and of the other silicates.

The deposit, first opened late in 1900, has been operated by open pit methods. Much of the deposit can be removed from the surface before underground mining becomes necessary.

The three other alteration lenses nearby appear to be smaller and generally less completely altered than the one described above. They lie to the northeast of it; all four are reached by the same road. At several other localities along the northern part of the East Crest carbonate strata have been partly to thoroughly silicated. These contain numerous prospect pits and trenches, but none has been actively mined.

REFERENCES

Adams, F. D. (1894) On the occurrence of a large area of nepheline-syenite in the township of Dungannon, Ontario: Am. Jour. Sci., vol. 148, pp. 10-16.

Adams, F. D., and Harrington, B. J. (1896) On a new alkali hornblende and a titaniferous andradite from the nepheline-syenite of Dungannon, Hastings County, Ontario: Am. Jour. Sci., vol. 151, pp. 210-218.

Anderson, G. H. (1937) Granitization, albitization, and related phenomena in the northern Inyo Range of California-Nevada: Geol. Soc. America Bull., vol. 48, pp. 1-74.

Anhury, L. E. (1908) The copper resources of California: California Min. Bur. Bull. 50, 366 pp.

Ball, S. H. (1907) A geologic reconnaissance in southwestern Nevada and eastern California: U. S. Geol. Survey Bull. 308, 218 pp.

Bisat, W. S. (1924) The Carboniferous goniatites of the north of England and their zones: Yorkshire Geol. Soc., Proc., n. ser., vol. 20, pp. 40-124.

Campbell, C. D. (1939) The Kruger alkaline syenites of southern British Columbia: Am. Jour. Sci., vol. 237, pp. 527-549.

Chayes, Felix (1942) Alkaline and carbonate intrusives near Bancroft, Ontario: Geol. Soc. America Bull., vol. 53, pp. 449-511.

Cooper, G. A., et al. (1942) Correlation of the Devonian sedimentary formations of North America: Geol. Soc. America Bull., vol. 53, pp. 1729-1794.

Daly, R. A. (1933) Igneous rocks and the depths of the earth, 508 pp. New York, McGraw-Hill Book Co.

Fairbanks, H. W. (1894) Preliminary report on the mineral deposits of Inyo, Mono, and Alpine Counties, California: California State Min. Bur. Rept. 12, pp. 472-478.

Fairbanks, H. W. (1896) Notes on the geology of eastern California: Am. Geologist, vol. 17, pp. 63-74.

Gilbert, G. K. (1875) Report on the geology of the portions of Nevada, Utah, California, and Arizona: U. S. Geog. Geol. Surveys West of the 100th Meridian, vol. 3, pp. 17-187.

Girty, G. H. (1909) The fauna of the Caney shale of Oklahoma: U. S. Geol. Survey Bull. 377, 106 pp.

Goddard, E. N., et al. (1948) Rock-color chart, Nat. Research Council, Washington, D. C.

Graham, R. P. D. (1909) On the optical properties of hastingsite from Dungannon, Hastings County, Ontario: Am. Jour. Sci., vol. 178, pp. 540-543.

Hague, Arnold (1883) Abstract of report on the geology of the Eureka district, Nevada: U. S. Geol. Survey 3d Ann. Rept., pp. 237-290.

Hazzard, J. C. (1937) Paleozoic section in the Nopah and Resting Springs Mountains, Inyo County, California: California Jour. Mines and Geology, vol. 33, pp. 273-339.

Hazzard, J. C. (1951) Revision of Devonian and Carboniferous sections, Nopah Range, Inyo County, California (abstract): Geol. Soc. America Bull., vol. 62, p. 1503.

Hewett, D. F. (1931) Geology and ore deposits of the Goodsprings quadrangle, Nevada: U. S. Geol. Survey Prof. Paper 162, 172 pp.

Hopper, R. H. (1939) Paleozoic section in the Argus and Panamint Ranges, Inyo County, California (abstract): Geol. Soc. America Bull., vol. 50, p. 1952.

Hopper, R. H. (1947) Geologic section from the Sierra Nevada to Death Valley, California: Geol. Soc. America Bull., vol. 58, pp. 393-432.

Jenkins, O. P. (1938) Geologic map of California, scale 1:500,000: California Div. Mines.

Johannsen, Albert (1932) A descriptive petrography of the igneous rocks; vol. 2, The quartz-bearing rocks, 428 pp., Chicago Univ. Press.

King, Clarence (1878) U. S. Geol. Expl. 40th Par. Rept., vol. 1, Systematic geology, 803 pp.

Kirk, Edwin (1948) Stratigraphy of the Inyo Range, pp. 19-48, in Knopf, Adolph, A geologic reconnaissance of the Inyo Range and the eastern slope of the southern Sierra Nevada, California: U. S. Geol. Survey Prof. Paper 110, 130 pp.

Kirk, Edwin (1933) The Eureka quartzite of the Great Basin region: Am. Jour. Sci., 5th ser., vol. 26, pp. 27-44.

Knopf, Adolph (1918) A geologic reconnaissance of the Inyo Range and the eastern slope of the southern Sierra Nevada, California: U. S. Geol. Survey Prof. Paper 110, 130 pp.

Krauskopf, K. B. (1941) Intrusive rocks of the Okanogan Valley and the problem of their correlation: Jour. Geology, vol. 49, pp. 1-53.

Larsen, E. S., Jr. (1948) Batholith and associated rocks of Corona, Elsinore, and San Luis Rey quadrangles, southern California: Geol. Soc. America, Mem. 29, 182 pp.

Longwell, C. R. (1949) Structure of the northern Muddy Mountain area, Nevada: Geol. Soc. America Bull., vol. 60, pp. 923-967.

Longwell, C. R. (1950) Tectonic theory viewed from the Basin Ranges: Geol. Soc. America Bull., vol. 61, pp. 413-433.

McAllister, J. F. (1940) Melanite-nepheline syenite from the Panamint Range, California (abstract): Geol. Soc. America Bull., vol. 51, p. 1961.

McAllister, J. F. (1940) *Palaeocyclus porpita*, Silurian coral from the Panamint Range, California (abstract): Geol. Soc. America Bull., vol. 51, pp. 1984-1985.

Mendenhall, W. C. (1909) Some desert watering places in southeastern California and southwestern Nevada: U. S. Geol. Survey Water-Supply Paper 224, 98 pp.

Merriam, C. W. (1940) Devonian stratigraphy and paleontology of the Roberts Mountains region, Nevada: Geol. Soc. America Special Paper 25, 114 pp.

Merriam, C. W., and Anderson, C. A. (1942) Reconnaissance survey of the Roberts Mountains, Nevada: Geol. Soc. America Bull., vol. 53, pp. 1675-1727.

Miller, A. K., and Furnish, W. M. (1940) Studies of Carboniferous ammonoids: Jour. Paleontology, vol. 14, pp. 356-377.

Murdoch, Joseph, and Webb, R. W. (1948) Minerals of California: California Div. Mines Bull. 136, 402 pp.

Murphy, F. M. (1932) Geology of a part of the Panamint Range, California: California Div. Mines Rept. 28, pp. 329-356.

Noble, L. F. (1934) Rock formations of Death Valley, California: Science, n. s., vol. 80, pp. 173-178.

Noble, L. F. (1941) Structural features of the Virgin Spring area, Death Valley, California: Geol. Soc. America Bull., vol. 52, pp. 941-999.

Nolan, T. B. (1929) Notes on the stratigraphy and structure of the northwest portion of Spring Mountain, Nevada: Am. Jour. Sci., 5th ser., vol. 17, pp. 461-472.

Nolan, T. B. (1943) The Basin and Range province in Utah, Nevada, and California: U. S. Geol. Survey Prof. Paper 197-D, pp. 141-196.

Norman, L. A., Jr., and Stewart, R. M. (1951) Mines and mineral resources of Inyo County: California Jour. Mines and Geology, vol. 47, pp. 17-223.

Peck, J. H., Jr. (1951) Nautiloid *Rayonnoceras* in California (abstract): Geol. Soc. America Bull., vol. 62, p. 1523.

Plummer, F. B., and Scott, Gayle (1937) Upper Paleozoic ammonites in Texas: Texas Univ. Bull. 3701, 516 pp.

Quensel, Percy (1914) The alkaline rocks of Almunge: Upsala, Univ., Geol. Inst. Bull. 12, pp. 127-200.

Shand, S. J. (1949) Eruptive rocks, their genesis, composition, classification, and their relation to ore deposits, 3d ed., 488 pp. New York, John Wiley & Sons.

Spencer, A. C. (1917) The geology and ore deposits of Ely, Nevada: U. S. Geol. Survey Prof. Paper 96, 189 pp.

Spurr, J. E. (1903) Descriptive geology of Nevada south of the 40th parallel and adjacent portions of California: U. S. Geol. Survey Bull. 208, 229 pp.

Stock, Chester, and Bode, F. D. (1935) Occurrence of lower Oligocene mammal-bearing beds near Death Valley, California: Nat. Acad. Sci. Proc., vol. 21, pp. 571-579.

Swartz, C. K., et al. (1942) Correlation of the Silurian formations of North America: Geol. Soc. America Bull., vol. 53, pp. 533-538.

Turner, H. W. (1902) A sketch of the historical geology of Esmeralda County, Nevada: Am. Geologist, vol. 29, pp. 261-272.

Waring, C. A. (1917) Geological map of Inyo County, California: California State Min. Bur.

Weller, J. M., et al. (1948) Correlation of the Mississippian formations of North America: Geol. Soc. America Bull., vol. 59, pp. 91-196.

Westgate, L. G., and Knopf, Adolph (1932) Geology and ore deposits of the Pioche district, Nevada: U. S. Geol. Survey Prof. Paper 171, 79 pp.

White, D. C. (1940) Antimony deposits of the Wildrose Canyon area, Inyo County, California: U. S. Geol. Survey Bull. 922-K, pp. 307-325.

Whitney, J. D. (1865) Geological Survey of California, vol. 1, Geology, 498 pp.

Wilmarth, M. G. (1938) Lexicon of geologic names of the United States: U. S. Geol. Survey Bull. 896, 2396 pp.

Winchell, A. N. (1951) Elements of optical mineralogy; Pt. 2, Descriptions of minerals, 4th ed., 551 pp. New York, John Wiley & Sons, Inc.

Youngquist, Walter (1949) The cephalopod fauna of the White Pine shale of Nevada: Jour. Paleontology, vol. 23, pp. 276-305.

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DIVISION OF MINES
OLAF P. JENKINS, CHIEF

STATE OF CALIFORNIA
DEPARTMENT OF NATURAL RESOURCES

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

SPECIAL REPORT 25
PLATE I

GEOLOGIC AND TOPOGRAPHIC SKETCH MAP
OF THE
QUARTZ SPRING AREA
PANAMINT RANGE, CALIFORNIA

0 2000 4000 6000 Feet

Contour interval 100 feet
Datum is approximately sea level

To Death Valley
Ubehebe Craters
15 mi.

To The Racetrack
5 mi.

(Ubehebe Peak Quadrangle)

36°45'

117°30'

To Lost Burro Mine

To Goldbelt Spring

Tihvipah Spring

Burro Spring

Rest Spring

Quartz Spring

Whitetop Mt.

Redlands Canyon

Rest Spring Gulch

Leadmine Rock Canyon

GAP HILLS

ANDY HILLS

HIDDEN VALLEY

DEATH VALLEY

RACETRACK

16½°E
True North
Magnetic North

BM 5330 HILL

BM 5980

EXPLANATION

SEDIMENTARY ROCKS

Qal	Alluvium and older gravel	QUATERNARY
Cl	Tihvipah limestone*	CARBONIFEROUS — Pennsylvanian
Crs	Rest Spring shale*	
Cp	Perdido formation*	CARBONIFEROUS — Mississippian
Clm	Tin Mountain limestone*	
Dlb	Lost Burro formation*	SILURIAN DEVONIAN — Lower, Middle (?) and Upper Devonian
Shv	Hidden Valley dolomite*	
Oes	Ely Springs dolomite	ORDOVICIAN — Upper Ordovician
Oe	Eureka quartzite	ORDOVICIAN — Middle Ordovician
Op	Pogonip limestone	ORDOVICIAN — Lower Ordovician
€n	Nopah formation	CAMBRIAN — Upper Cambrian
€r	Racetrack dolomite*	CAMBRIAN — Middle(?) Cambrian

IGNEOUS AND METAMORPHIC ROCKS

Syenite and associated intrusive rocks

ump — Undifferentiated metamorphic Paleozoic rocks

25 — Contact, showing dip (Dashed where approximately located)

U 0 D ↕ 80 — Fault, showing dip (U, upthrown side; D, downthrown side; dashed where approximately located; dotted where concealed)

Probable fault

Thrust fault (T, upper plate; dashed where approximately located)

50 — Strike and dip of beds

60 — Strike and dip of overturned beds

* NEW FORMATION

Shaft · Adit · Mine · Prospect
Cu = copper F = fluorite
t = tremolite rock

Geology and topography mapped by J. F. McAllister
1938

Culture revised
1951

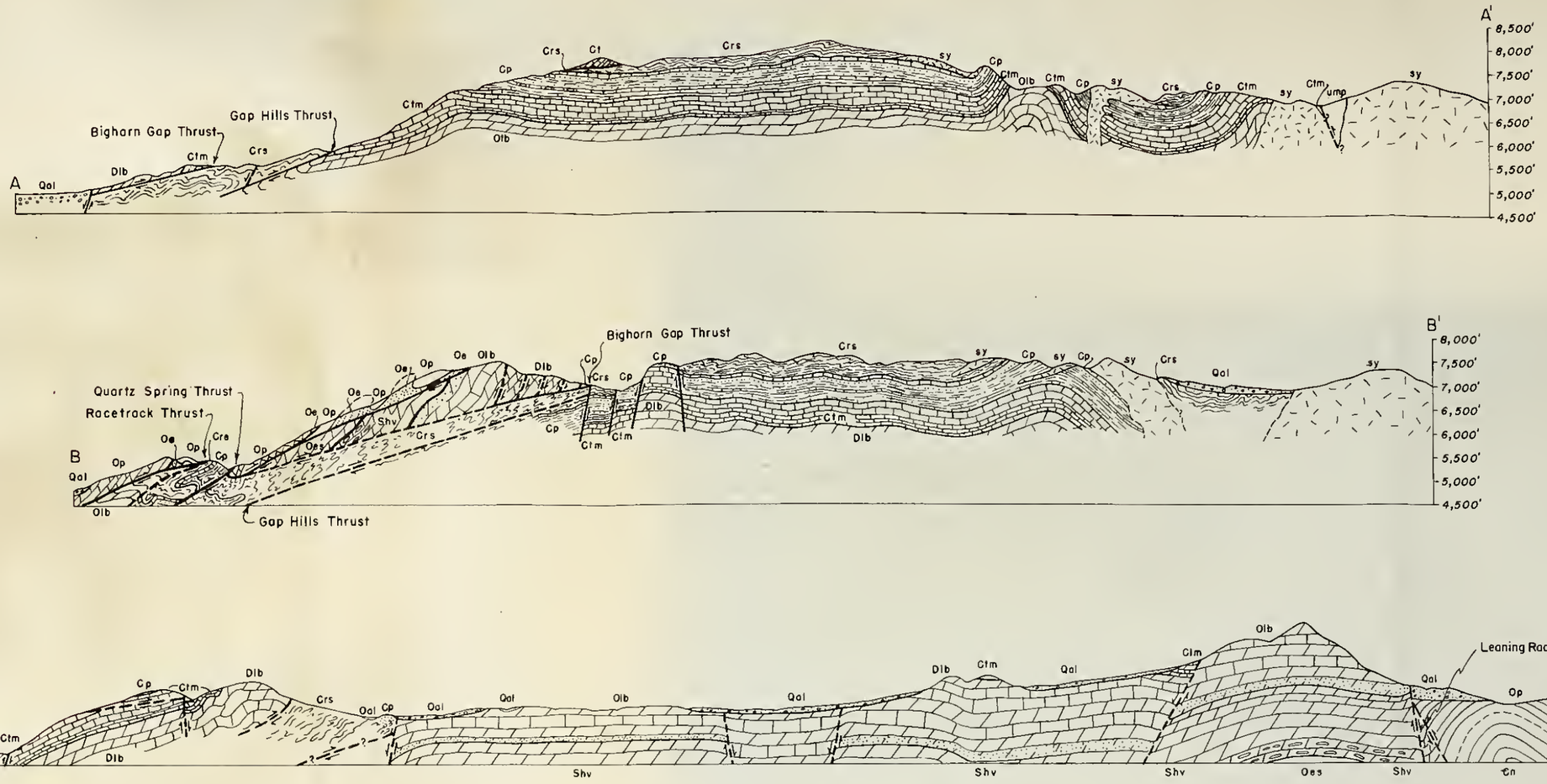
UNITED STATES DEPARTMENT OF THE INTERIO
GEOLOGICAL SURVEY
STATE OF CALIFORNIA
DEPARTMENT OF NATURAL RESOURCES

DIVISION OF MINES
OLAF P. JENKINS, CHIEF

SPECIAL REPORT 25
PLATE 2

Age	Formation	Lithology	Fossils	Locality of measured section
CARBONIFEROUS 1,595 FT. — Penn.	TIHVIPAH LIMESTONE 200± FT.	Limestone, shaly limestone, calcareous shale: mostly platy and light gray; some massive, medium gray chert in spheroidal concretions, very dark gray.	Fusulinids	1–2 miles N. 80° W. of Ubehebe mine
Penn.(?)	REST SPRING SHALE 310± FT.	Siltstone, shale, a little quartzite: olive gray to olive brown. Shale: olive gray and dark gray, weathering olive gray; discoidal concretions.	Poorly preserved Brachiopods suggestive of Chonetes, Marginifera, Composita	3 miles N. 70° E. of southwest corner of Ubehebe Peak quad.
Mississippian	PERDIDO FORMATION 610± FT.	Siltstone, shale, limestone, chert, conglomerate: pale red to dark gray, weathering reddish brown, brown or gray; siltstone predominant in upper part, limestone predominant in lower part, characterized also by beddad chert.	Cravenaceras Dictyoclostus? sp. indet. Rhyncopora? sp. indet. Composita? sp. indet. Caninia cf. C. cornicula (Millar)	Upper part: 3,000 feet south at Rest Spring. Remainder: 9,000 feet southeast of Quartz Spring.
	TIN MOUNTAIN LIMESTONE 475 FT.	2 Limestone: medium gray; pale red shaly partings; some chert nodules. 1 Limestone: medium gray; in thin beds; interbedded with calcareous shale light brownish gray to pale red; some chert nodules.	Spirifer cf. S. centronotus Winchell Syringopora cf. S. oculeata Girty S. cf. S. surcularia Girty	About 2½ miles southeast of Quartz Spring
DEVONIAN 1,590 FT. — Upper and Middle(?)	LOST BURRO FORMATION 1,525 FT.	5 Sandstone, quartzite, sandy dolomite: very light gray, sandy parts weathering brown. 4 Dolomite: very light gray; some medium gray, interbedded. 3 Dolomite and limestone: very dark gray and light gray, alternately. 2 Dolomite; light gray, mottled and streaked creamy; very dark gray, some mottled with lighter gray. 1 Sandy and shaly dolomite; light gray, weathering mouse gray to brown, some chert nodules.	Cyrtospirifer cf. C. monticola (Haynes) C. cf. C. disjunctus (Sowerby) Tylothyris? cf. T.? raymondi Haynes "Camarotoechia" aff. "C." duplicata (Hall) Glaiothyridina cf. G. devonica Raymond Productella sp. Bryozoa and corals Atrypa sp. Cladopora Stromatopora	Type locality west side at south end of Lost Burro Gap between Racetrack Valley and Hidden Valley starting about 3 miles S. 25° W. of Quartz Spring
Lower	HIDDEN VALLEY DOLOMITE 1,365 FT.	3 Dolomite: medium dark gray, weathering light olive gray; fossils in upper 65 feet in Andy Hills, Hidden Valley. 2 Dolomite: very light gray; massive. 1 Dolomite: medium gray and medium light gray; cherty.	Papiliaphyllum elegantulum Stumm Breviphyllum lanensis (Stumm) Breviphrantis invaginatus (Stumm) Acrospirifer kobehana (Merriam) Meristella robertsensis Merriam Halysites catenularia (Linnaeus) H. microporus (Whitfield) Favosites cf. F. niagarensis Hall F. aff. F. gothlandica Porpites aff. P. porpita (Linnaeus)	Type locality about 2½ miles north of Ubehebe Peak
SILURIAN 1,300 FT. — Upper	ELY SPRINGS DOLOMITE 940 FT.	2 Dolomite: light gray, grading downward to medium gray; some darker mottling. 1 Dolomite: conspicuously dark gray; in detail, mottled lighter gray; chert nodules.	Streptelasma sp. Halysites sp. Rosserella sp. Dinorthis aff. D. subquadrata (Hall) Rhynchotrema cf. R. argenturbicum (White) R. aff. R. capax (Conrad) Zygospira cf. Z. modestus (Say)	About 2½ miles north of Ubehebe Peak
Middle	EUREKA QUARTZITE 400 FT.	2 Quartzite: vitreous, weathering light tints of yellow and pink. 1 Quartzite, hematitic, limonitic and vitreous, interbedded with a little siltstone, dull light gray.	No fossils	About 2½ miles north of Ubehebe Peak
ORDOVICIAN 2,780±FT. — Lower	POGONIP LIMESTONE 1,440 FT.	8 Dolomite, some sandy dolomite and dolomitic sandstone in local beds: generally medium gray, some dark gray. 7 Shaly limestone: light buff or yellowish. 6 Siliceous (largely cherty) limestone: gray, weathering brown; crepe structure. 5 Shale: light brown. 4 Siliceous limestone and dolomite: light gray, weathering brown. 3 Shaly dolomite: gray, weathering buff. 2 Dolomite: light gray, weathering in general light brown or light brownish gray. 1 Dolomite: medium gray; limestone, local; chert, light gray, in thin lenses.	Bryozoa Palliseria langwelli (Kirk) Maclurites sp. Receptaculites sp. Parambonites sp. Fragments Archaeorthis costellata Ulrich and Cooper Bellfontia sp. Hystricurus tuberculatus (Walcott) Kainella (?) finalis (Walcott)	Last Chance foothills, 2⅗ miles N. 75° W. of Quartz Spring
CAMBRIAN 3,500±FT. — Upper	NOPAH FORMATION 1,600 FT.	9 Dolomite: dark gray. 8 Dolomite: cream colored. 7 Dolomite: medium to dark gray. 6 Dolomite: cream colored. 5 Dolomite: dark gray. 4 Dolomite: light gray. 3 Dolomite: dark gray. 2 Dolomite: cream colored. 1 Dolomite: dark gray; lower part silty, some shaly partings, weathering to light browns.	Matherella cf. M. saratogensis Walcott Sinuopea spp. Strepsodiscus sp. Lingula sp. Obolus sp. Acrotreta cf. A. idahoensis Walcott Aphelaspis sp. Elvinia n. sp. Linnarssonella girlyi Walcott Pterocephalia ?	Last Chance foothills about 3 miles west of Quartz Spring
Middle (?)	RACETRACK DOLOMITE 1,900± FT.	7 Dolomite: light gray, grading into darker gray at base. 6 Dolomite: light greyish buff; a few thin dark beds. 5 Dolomite: very dark gray, irregular lighter mottling. 4 Dolomite: light gray, weathering creamy. 3 Dolomite: medium gray; closely spaced sinuous mottling; some chert nodules. 2 Dolomite: silty in part; weathering pale yellowish brown. 1 Dolomite: dark gray, irregularly banded lighter gray in layers about 1 inch thick. Some chert masses in upper part.	No fossils	Type locality Last Chance foothills about 3 miles west of Quartz Spring

COLUMNAR SECTION OF PALEOZOIC ROCKS IN THE QUARTZ SPRING AREA
NORTHERN PANAMINT RANGE, CALIFORNIA



GEOLOGIC STUCTURE SECTIONS, QUARTZ SPRING AREA, PANAMINT RANGE, CALIFORNIA

Qal, olluvium ond older grovel; Ct, Tihvipoh limestone; Crs, Rest Spring shole; Cp, Perdido formotion; Ctm, Tin Mountoin limestone; Dlb, Lost Burro formotion; Shv, Hidden Volley dolomite; Oes, Ely Springs dolomite; Oe, Eureko quartzite; Op, Pogonip limestone; €n, Nopoh formotion; €r, Racetrack dolomite; sy, syenite ond ossocioted intrusive rocks; ump, undifferentoted metamorphic Poleozoic rocks.